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CONSERVATION IRRIGATION

in Humid Areas

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AGRICULTURE HANDBOOK NO. 107
Soil Conservation Service
U. S. Department of Agriculture

Irrigation Is an Individual Matter

In humid areas, whether to irrigate is a question to be decided separately for each farm. The farmer must consider his own needs and resources, and weigh costs and benefits in relation to conditions on his own farm. Soil conservationists, engineers, county agents, and others who help farmers to plan their irrigation systems must take these local conditions into account. Each farm, each system is an individual matter.

To make the right decisions and design an efficient system for a particular farm, four things are needed:

(1) *A soil and land-capability map of the farm.* This map will tell what kind of soil occurs in each part of each field. It will show the capability of each soil for cultivation and irrigation, and its needs for conservation practices. In soil conservation districts each farmer can get a copy of this map from the district or the Soil Conservation Service office. Elsewhere, it will be necessary for someone skilled in soils to examine the farm and prepare the soil map.

(2) *A copy of the local Conservation Irrigation Guide.* This guide is a compilation of the best local information about soils and crops essential in planning the irrigation system. It tells such things as the water-holding capacity and intake rate of each soil, and the water-use rate of each crop. These factors vary so much from one place to another that reliable information cannot be put in a handbook of this kind. The local guides have been compiled by the Soil Conservation Service in cooperation with State experiment stations, Agricultural Research Service, county agents, and others who have such information. Soil Conservation Service offices have copies of these guides.

(3) *A conservation plan for the farm.* Successful irrigation must take into account the capability and needs of the soil. For continued profits, irrigation must be fitted into a basic soil conservation plan including a good soil management system. In soil conservation districts, many farmers will already have such a plan; those who do not can get help from the district in making them.

(4) *Expert help in designing the system.* Deciding the mechanical specifications of a system to fit a particular farm is a highly complicated engineering problem. Once the decision is made to proceed with an irrigation project, and the general features of the system are determined to fit into the general conservation plan of the farm, the planner needs the services of an expert in irrigation design. In soil conservation districts, engineers of the Soil Conservation Service are available for this work. Many equipment dealers employ engineers, and other agricultural specialists are qualified to help. But be sure to get expert help in designing the irrigation system.

This handbook cannot answer all the specific questions that arise in planning a farm irrigation system. It cannot give the local information needed to answer many of these questions. Rather, it presents basic information and principles of wide application, and seeks to guide the user through the analysis of an individual problem with the use of the local irrigation guides and services mentioned above.

And finally, no matter how sound the planning or how good the design, an irrigation system will not give good results unless it is operated correctly. To do this the irrigator must know the capabilities of his system and of his soils, and the water requirements of his crops. With this knowledge he can apply the principles of conservation irrigation to his own farm.

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Figure 1.—The humid area to which this handbook applies. Insets show typical rainfall patterns in comparison to monthly moisture needs of important crops at representative stations for a normal and a dry year. The peculiar features of humid-area irrigation give way to problems of arid agriculture from east to west through the transition zone.

CONSERVATION IRRIGATION IN HUMID AREAS

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IRRIGATION IN HUMID AREAS differs from irrigation in the arid West. Most important, production of cultivated crops is possible in a humid climate without irrigation; in an arid one it usually is not.

The line that divides humid from arid lands is not a sharp one. It is a broad transition zone running across Texas, Oklahoma, Kansas, Nebraska, and North and South Dakota (fig. 1). East of this zone is the humid area for which this handbook is written. To the west different conditions demand or permit different methods.

Within the transition zone itself, conditions change gradually from humid on the east to arid on the west. Irrigators in each locality will need to study their own situation carefully, to compare it to typical humid and arid conditions, and to judge which methods of irrigation offer the best promise of success. In every case they will gain by relying to the greatest possible extent on the results of local research and experience.

East of this zone, the average annual rainfall ranges from about 20 inches in western Minnesota to 60 inches in the Southeastern and Gulf States. In most of this area rainfall usually is sufficient to produce good yields of most farm crops. But the rainfall does not always fall at the time it is most needed (fig. 1). Frequent droughts in the growing season reduce the yield and quality of crops. Irrigation can overcome these deficiencies.

Conservation Irrigation Farming

The margin of profit between farming with and without irrigation is much smaller in humid than in arid areas. The humid-area farmer, therefore, must make sure he gets maximum returns from his investment to make irrigation profitable. This means that he must not only have an efficient irrigation system efficiently operated, but he must also use good soil conservation and farm management practices with it.

To use irrigation merely to rescue a crop already suffering from drought will do very little in the long run to increase crop production and profits. Good conservation farming practices without irrigation will usually pay off better than irrigation used as "crop insurance" without the soil-management practices needed with it.

Irrigation properly used in the humid area will eliminate the drought hazard from farming; then soil fertility and aeration, not moisture, become the major limiting factors in crop production.

The principles and methods of irrigation set forth in this handbook are designed for typical humid con-

ditions. They differ from arid-land irrigation in the following important ways:

(1) Every system must provide for safe use or disposal of surplus rainfall. This requires safeguards against soil erosion and provisions for surface drainage not ordinarily needed in arid areas.

(2) Seasonal water requirements are less than in arid climates, but short-time peak-use requirements may be as great.

(3) Farm crops generally do not root as deeply in humid as in arid areas. This necessitates more frequent but lighter irrigations during drought.

(4) Winter rain and snow completely replenish the soil moisture in most years so irrigation before planting or after harvest is unnecessary.

(5) The cost of land leveling often can be offset largely by benefits from improved drainage, a common need in humid areas.

(6) Humid-area soils generally have fine-textured subsoils at 6 to 24 inches depth. This often limits the extent of land leveling possible, and makes a thorough knowledge of soil conditions especially important to planning any grading or leveling.

Need for Irrigation

The average annual rainfall in humid areas would be sufficient to meet the total moisture requirements of most crops if properly distributed through the growing season. This ideal rainfall pattern seldom occurs, however, and many crops suffer even in so-called "normal" rainfall years (fig. 1).

Moreover, runoff from high-intensity storms and deep percolation to below the crop roots deprive growing plants of a large part of the total rainfall.

The effect of short droughts on crops in the humid area depends in part upon the kind of soil. A plant growing in a sandy soil may show early signs of drought, while the same plant in a silt loam may survive a dry period without damage. These differences affect the need for irrigation in each locality.

In dry years irrigation in humid areas is generally profitable, but in some years it gives little advantage. The farmer who is considering installing an irrigation system should not be influenced too much by reports of increased yields obtained by his neighbors or experiment stations during dry years. It is the average increase in yield over a long period, including both wet and dry years, that proves the true worth of irrigation.

The expected results from irrigation must, of course, be balanced against the cost of installing and operating the system. These costs will vary widely from farm to farm depending on such items as cost of developing a water supply, type of soil, topog-

raphy, method of irrigation selected, and the cost and availability of labor.

Benefits of Irrigation

Irrigation helps to stabilize the farm economy. During recent years the cost of farming has increased so greatly that few farmers can afford even one crop failure. The irrigator can make full use of seed, fertilizers, equipment, and labor every year with more consistent, and usually larger, harvests.

Besides increasing per-acre yields, proper use of irrigation can improve the quality of crops. By maintaining adequate moisture in the soil during the growing season, the farmer can produce higher quality crops demanding higher market prices.

Time of harvest also can be more closely controlled. In many highly competitive areas, the difference between profit and loss often hinges on the time certain crops are put on the market. Irrigation insures prompt germination and continuous plant growth, making it possible to regulate planting dates and time of maturity more closely.

With irrigation, fertilizers placed in the soil are available at once to plants because moisture is always present. Under these conditions larger amounts can be used. Soluble fertilizers can be applied through irrigation water with a saving in labor and equipment and with better control of placement in the root zone.

Certain high-value cash crops can be protected from frost damage with sprinkler irrigation.

Irrigation increases the survival of transplanted crops by settling the soil into close contact with the root system.

The efficient use of irrigation permits better use of land in accordance with its capability. It increases the capability of some soils for different uses. Increased per-acre yields on the good land permit devoting the more erodible land to grasses and legumes, wood crops, or other uses. Irrigation makes possible the successful seeding of needed cover or soil-improving crops at the proper season and helps in establishing vegetative cover on eroded areas (fig. 2).

Costs of Irrigation

Irrigation costs may be divided into (1) fixed costs and (2) operating and maintenance costs. Fixed

costs are all costs for which an initial outlay is made or a capital investment is extended, including taxes and insurance. Annual fixed charges include depreciation and interest on the capital investment. Annual operating and maintenance charges include all recurring costs, such as fuel or power, labor for water application and maintenance of the system, and repair of equipment.

Developing the water supply is a fixed expense for most irrigators. For those who can pump directly from a perennial stream, this is a minor expense. Where the source is a farm reservoir, the initial investment may be \$50 to \$200 per acre irrigated. The cost of drilling a deep well to obtain a specific flow of water, say 800 g. p. m., will range from a few hundred dollars in one locality to several thousand dollars in another.

For sprinkler irrigation, the greatest fixed cost usually is for the equipment, including pump and power unit, sprinkler heads, pipe and fittings, and accessories. Most portable irrigation systems, when adequately designed, cost from \$80 to \$200 per acre irrigated; a few cost more in unusual conditions.

Land-leveling costs for surface irrigation usually range from \$25 to \$100 per acre.

Many factors affect the initial cost of an irrigation system. Some of the more important ones are:

(1) The nearness of the water supply to the irrigated area affects the length and size of main-line pipe or ditch required. The closer the water supply, the less it costs to get the water to the irrigated area.

(2) Difference in elevation between the area to be irrigated and the water supply determines the static lift, which in turn affects the size of pump and horsepower of the motor needed.

(3) The size of the area to be irrigated influences the per-acre costs of equipment and land leveling. Other factors being equal, the smaller the area irrigated the greater is the cost per acre. This is particularly true of areas of less than 5 or 10 acres.

(4) Control equipment that permits continuous operation adds considerably to the cost of sprinkler systems. These items usually include extra lateral lines that can be moved while the system is operating, and the valves and other fittings required at takeoff points on the main line. The cost of this equipment is usually more than offset by a saving in labor.

(5) The number of hours each day the system is designed to operate affects the per-acre cost for equipment. A sprinkler system designed to cover an area in a certain number of days operating 10 hours daily costs nearly twice as much as one designed to cover the same area in the same period operating 20 hours daily.

Annual costs for power depend upon the type of power unit used, the cost of fuel or electricity, and the overall efficiency of the pumping plant. Except for electricity, the power cost varies directly with the horsepower delivered and the number of hours operated during the season. Electric power rates usually consist of a fixed or minimum charge, based



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Figure 2.—Irrigation makes possible the growing of perennial grasses or legumes to control erosion.

on the horsepower rating of the motor, and a diminishing schedule of rates for energy actually consumed. The cost of electric power per hour of operation, therefore, usually declines as the number of hours of operation increases.

Labor costs vary widely. Operation of a sprinkler system usually requires from $\frac{1}{2}$ to 2 man-hours of labor per acre per irrigation. Some of the factors that influence labor costs are: Spacing of the lateral lines; height, density, and planting pattern of the irrigated crop; walking conditions in the irrigated area; the amount of water applied at each irrigation in relation to the total amount applied during the season; and, of course, the design of the system itself.

A well-planned sprinkler system with lateral lines rotated to minimize the haul-back of pipe to the starting position reduces labor costs. Buried main lines with hydrant valves at each lateral position eliminate the cost of laying and taking up main-line pipe. Extra lateral lines that can be moved while the system is operating help keep labor occupied. The use of mechanized equipment for moving lateral lines eliminates most of the labor required for this operation, but adds to the initial cost of equipment.

Maintenance costs include lubrication and maintenance of the pump and power units, cleaning and storing of pipe, replacement of worn coupler rings, and repairs to sprinkler heads and valves. Annual land smoothing is usually necessary where surface irrigation is used.

As can be seen from the foregoing discussion, a satisfactory cost estimate for irrigation on any individual farm can be made only after due consideration of all the factors involved.

Requirements for Successful Irrigation

Some of the requirements for successful irrigation are:

Land capability.—Irrigation should be confined to soils that are capable of producing sustained high yields of adapted crops when properly treated and managed.

The capacities and limitations of each soil for storing moisture and plant nutrients, for withstanding grading in land preparation, and other features affecting irrigation design, must be taken into account.

Adequate water supply.—A supply of water adequate to meet the needs of the crops being irrigated must be available when needed.

Adequate labor.—The addition of irrigation to other farm operations materially increases labor requirements on most farms in the humid area. Often one or more crops need to be irrigated at a time when other crops must be planted, cultivated, or harvested. Adequate labor must be available when required for efficient operation of the system.

Adequate capital.—Irrigation is an expensive practice compared with most farming operations. This fact should be kept in mind when considering



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Figure 3.—Benefits of irrigation are lost where unprotected soil erodes.

irrigation. The owner must be able to make an initial capital investment adequate to install a well-designed system planned to meet his individual needs. He must have enough capital to operate and maintain the system at least until the first year's irrigated crop is marketed.

Erosion control.—High yields of irrigated crops cannot be sustained on eroding land. For this reason, irrigation should not be planned on land subject to erosion until erosion-control measures have been established (figs. 3 and 4). These measures may include terracing, contour cultivation, stripcropping, and the use of cover crops. The erosion-control practices and the irrigation system need to be fitted together to provide ease of operation and uniform distribution of water.

The hazards of erosion may be increased by



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Figure 4.—A complete conservation program is essential to successful irrigation.

irrigation in the humid area. Land under irrigation is subject to the effect of natural rainfall as well as irrigation water. A heavy rainstorm immediately following irrigation may cause excessive runoff and carry away valuable soil and plant nutrients.

If sprinkler irrigation is used, the water-application rate must be no faster than the soil can absorb the water. Excessive rates of application will cause surface runoff.

The size of the drops also is important. Large drops dislodge particles of soil that can easily be carried away by runoff water. On bare fields or new seedlings and row crops, rain and sprinkler irrigation water may compact and seal the soil surface. This reduces the soil's ability to absorb water and increases the erosion hazard. Where crop cover or mulch is present, the energy of falling water is dissipated and little or no surface sealing or erosion results.

Some movement of soil particles occurs wherever water flows over loose soil. This happens when irrigation water is applied to furrows or borders immediately after cultivation. By using small streams of water on gentle slopes, erosion can be kept to a minimum.

Adequate drainage.—Effective drainage, both surface and internal, is essential to successful irrigation in humid areas. There is little point in irrigating a crop during the early part of its growing season only to have it damaged by poor drainage before it reaches maturity.

Where the land is not naturally well drained, artificial drainage must be provided before the irrigation system is installed. Most poorly drained soils will benefit more from good drainage without irrigation than they will from irrigation without drainage.

Soil management.—A system of soil management that maintains good tilth and soil fertility are essential to successful irrigation. This is necessary not only for maximum crop yields but also to insure proper soil structure for irrigation water to soak in and be held by the soil.

High fertility levels.—Maximum yields do not result from the application of water alone, but from adequate air and moisture combined with adequate plant nutrients. For this reason, a high level of fertility must be maintained by the liberal use of soil-improving crops, barnyard manures, and commercial fertilizers.

High plant population.—To get the most benefit from irrigation the number of plants per acre needs to be as great as can be produced without impairing the growth of individual plants. It is usually profitable to increase the seeding rate or density of stand of most crops when changing to irrigated farming. Only those crops and varieties best adapted to local soils and climatic conditions should be used.

Control of plant diseases and insects.—Plant diseases are sometimes aggravated when irrigation water is applied directly to the foliage by sprinkler irrigation. Disease-resistant varieties of crops should be used where available. Repeated spraying or dusting may be necessary to control insects. With sprinkler

irrigation, insecticides should be applied as soon as practical after each irrigation.

Planning the Irrigation System

Irrigation, like any other farm operation, should be undertaken only if it can be done successfully and at a profit. The benefits must increase farm income enough to cover the costs of purchasing, installing, operating, and maintaining the irrigation system and leave a reasonable return on the owner's investment.

Moisture alone will not assure high yields of any crop, and successful irrigation involves more than putting water on the land when rain fails. The water must be applied to meet the growth requirements of the crops on the soils involved. Fertility levels must be maintained and soil resources preserved for future production.

To avoid costly mistakes, the farmer must consider first whether irrigation is feasible on the farm. This decision made, he needs to develop a sound plan for using irrigation as a part of his total farm operation. Finally, he needs a correct design for the system to meet the exact conditions on his farm.

Such an irrigation plan calls for careful surveys of conditions on the farm; for reliable information on the soils, crops, and adapted irrigation practices for the area; and, usually, for technical services in designing the system. The resulting plan needs to be coordinated with the conservation plan for the farm.

Surveys for planning

Sound planning and design of an irrigation system to fit all the foregoing variable factors requires careful inventory of the conditions on the individual farm. Such an inventory is needed to (1) determine the feasibility of irrigating; (2) select the most adaptable and efficient method of water application; (3) provide a basis for the location and design of field distribution systems, ditches, pipelines, structures, and pumping plants; and (4) provide information for the effective operation of the irrigation system.

The surveys normally needed include:

Water-supply inventory.—The water-supply inventory consists of finding out what the possible sources are and the rates and quantities available at each. Variations in supply from one season to another should be determined. If the supply declines during the growing season, it should be studied by months, or shorter periods, in relation to crop requirements.

Soil surveys.—Irrigation planning requires an accurate soil survey giving special attention to conditions that affect the application and retention of water. The survey usually is plotted on an aerial photograph and enlarged to the scale of the topographic maps used.

In addition to showing the kinds of soil and other physical conditions that affect land capability, the survey should get facts needed in designing the

irrigation system. It should indicate the general condition of the topsoil, including structure, organic-matter content, and other factors which might influence rate of water intake.

The texture and permeability of each layer of the subsoil should be known. This information indicates the freedom with which water and air can move through the profile and the ability of the soil to retain moisture within the root zone of crops.

The depth of the soil profile and any possible restriction to the penetration of plant roots should be known. Where land leveling may be needed, the depth to which the soil can safely be disturbed must be known.

Kinds of soil must be accurately drawn on the map. The location and extent of soils that differ widely need to be considered in deciding how an area might be subdivided, if necessary, so that different methods of application and different amounts of water can be used at each irrigation.

Any other soil conditions that might affect the practice of irrigation should be shown, such as high water table, restrictions to adequate drainage, erosion hazards, plow soles or compacted areas, or high salt content.

Topographic survey.—The kind of topographic surveys needed depends upon the method of irrigation to be used and the irregularity of the ground surface. Detailed topographic surveys are time-consuming and expensive; only enough information need be obtained to permit sound and accurate planning. Usually a careful inspection of an area will reveal the nature and extent of surveys needed.

Any topographic survey begins with a base map showing the boundaries and dimensions of the fields to be irrigated and the location of the water supply. Such a map can be made by enlarging an aerial photograph to the desired scale—usually 50 to 200 feet to the inch—and tracing from the enlargement.

For planning sprinkler irrigation, the topographic information needed ordinarily includes only such elevations as will: (1) Show direction of land slopes for locating laterals and main lines; (2) show changes in elevation along lateral-line settings so the system can be designed to control variations in sprinkler discharge; and (3) show maximum differences in elevation along the main line and between the irrigated area and the water source. Where slopes are gentle and fairly uniform, a few elevations taken along the sides of the field, at control points along possible main-line locations, and at the water source will be sufficient. On rolling land or wherever lateral lines must follow contour rows, or on level land where surface drainage is a problem, a more detailed survey and a contour map are needed.

For surface or subirrigation methods not involving land leveling, a less detailed survey will suffice. The planner needs only those elevations that show the natural ridges, depressions, and other features that influence the location of contour border ridges, subirrigation laterals, field supply ditches, and drainage ditches.

For graded border, furrow, or other methods

requiring land leveling, a complete topographic survey is required. Such a survey is usually made by obtaining elevations in a grid at 100-foot intervals parallel and at right angles to the proposed direction of irrigation. Stakes set at each grid corner are marked later and used as grade stakes as a guide in leveling.

Where open ditches or permanent buried pipelines are to be used to carry water from the source to the field supply ditches, their location should be determined by a standard route-type survey. A profile of each proposed centerline is needed. For computing amount of excavation, cross sections need to be surveyed at intervals not exceeding 100 feet along the centerline.

Sources of power.—Sources of power available for use with the system need to be determined and compared. Where electric power is available, the location of the nearest transformer, and features such as phase, voltage, and horsepower limitations, should be noted. Particular attention should be paid to the schedule of power rates and standby charges.

Crop enterprises.—The crop enterprises should be determined as closely as possible. The type, acreage, and definite field boundaries for each crop should be considered in relation to rotations planned. Cover and soil-improving crops need to be taken into account in estimating water requirements.

Farm operation schedules.—A clear picture of farm operation schedules is needed to know how much time can be devoted each day to irrigation without neglecting other work. This information should show if full-time irrigators are required during the growing season or if incidental labor can be used at different times of the day or night.

Choosing method of irrigation

The results of the foregoing survey will indicate the method of irrigation best suited to the farm. Three general types are used in the humid area: (1) Sprinkler irrigation, (2) surface irrigation, and (3) subirrigation. Three methods of surface irrigation are common; namely, furrows, contour borders, and graded borders.

Each method is applicable to a particular set of conditions; none can be used successfully under all conditions. The principal features of the methods adapted to humid conditions are as follows:

Sprinklers.—Water is sprayed through the air to cover the landlike rainfall.

CROPS: All crops except rice.

SOILS AND TOPOGRAPHY: Any irrigable soil with topography suitable for cultivation or for growing perennial grasses and legumes.

IMPORTANT FEATURES: The method gives good control of water application and generally good efficiency; provides uniform wetting; can be used on steep slopes; land leveling is not required unless needed for drainage; initial costs are high; water distribution is adversely affected by wind; power required to operate sprinklers adds to cost.

Furrows.—Water flows down furrows between the crop rows.

CROPS: Row crops such as corn, cotton, soybeans, truck crops, tree fruits, small fruits, and vineyards.

SOILS AND TOPOGRAPHY: All soils except coarse-textured ones that take water rapidly, on slopes where furrow grades can be less than 0.5 foot per 100 feet.

IMPORTANT FEATURES: The method is adapted to variable stream sizes; gives generally good efficiency; provides good surface drainage; permits slight variations in furrow slope; portable and permanent pipelines eliminate need for ditches; gated pipe and siphons give positive control in distribution; land leveling is required for good distribution of water; irrigation water does not wash insecticides off foliage.

Contour borders (rice levees).—Contour ridges confine water on the land.

CROPS: Rice, pasture grasses, hay crops, small grain, and row crops that can be flooded.

SOILS AND TOPOGRAPHY: Medium- to fine-textured soils with smooth, reasonably uniform slopes of not more than 1 foot per 100 feet.

IMPORTANT FEATURES: The method gives high irrigation efficiency and good surface drainage; large streams of water are required; land preparation costs are low; labor requirements are low; border ridges or levees interfere with farming operations.

Graded borders.—Parallel ridges control the flow of water down gentle slopes.

CROPS: Pasture grasses, hay crops, and small grains.

SOILS AND TOPOGRAPHY: Medium- to fine-textured soils on smooth slopes of not more than 2 feet per 100 feet.

IMPORTANT FEATURES: The method gives good irrigation efficiency and good surface drainage; medium to large streams of water are required; land leveling costs are generally high; labor requirements are low; border ridges interfere with farming operations; border pattern fits in well with furrow irrigation in a crop rotation on slopes of less than 0.5 foot per 100 feet.

Subirrigation: A water table is kept at a controlled depth below the soil surface.

CROPS: All crops with shallow or medium root depths, except rice.

SOILS AND TOPOGRAPHY: Very permeable soils underlain with impermeable barrier or high water table and with nearly level topography.

IMPORTANT FEATURES: Installation costs are low except where the lines are used; labor requirements are low; drainage is good; land leveling or smoothing is usually required. The method is adapted to limited areas.

Design and operation of the system

The irrigation system, regardless of type, must be carefully designed to fit the soil, climate, topography, and available labor on the individual farm where it is to be used. In many years the difference between a well-designed and a poorly designed system will mean the difference between profit and loss.

Good design is not enough to insure maximum returns from an irrigation system. Operation in accordance with the standards used in the design is also essential. Many well-designed systems have failed because they were not used properly. In order to operate his system properly, each farmer must know the intake rate, depth, and water-holding capacity of his soil. He needs to be able to determine the moisture content of his soil and must be willing to irrigate when the soil needs water without waiting for a rain that may not come.

Conservation irrigation guides

Irrigation design must be based on accurate information about the soils of the field to be irrigated and water-use requirements of the crops to be grown. These vary so much from one locality to another that local information must be used to be sure the design will fit the conditions on the farm. Such local information is available in most soil conservation districts and counties in the form of Conservation Irrigation Guides.

These guides are developed cooperatively by the Soil Conservation Service, Agricultural Research Service, Extension Service, and Experiment Stations. They are prepared for each local area having similar soils and nearly uniform water requirements for crops. A group of soil, plant, and irrigation specialists acquainted with each area makes a complete search of all available research information, analyzes field studies, and reviews successful irrigation experiences to obtain the best local information about soils and crops and their management under irrigation.

The Conservation Irrigation Guide tells the available moisture-holding capacity and intake rate of each soil type. It gives peak water-use rates and recommended depths to irrigate for different crops. The guide recommends the adapted methods of irrigation and gives the following types of information for each situation: (1) Needed frequency of irrigation for different crops during season of peak water-use rates, (2) probable field efficiencies of the irrigation systems, (3) the amount of water that the system should be designed to apply at each irrigation, and (4) the estimated time required to apply this amount of water. Figure 5 is an example of an irrigation guide from Missouri.

Moisture in the Soil

To plan a conservation irrigation system for a particular farm, and to operate the system to keep the crops growing at an optimum rate, information is needed on the capacity of the soil to take up and retain water and the rooting habits and water requirements of the crop to be irrigated.

The soil may be considered as a reservoir for soil moisture and plant nutrients. The roots of the plant correspond to a pump with many inlets that penetrate deeper into the reservoir as the crop grows. But the character of the plant limits the extent of

Conservation Irrigation Guide for Missouri

Soils				Crops*				Irrigation specifications					Furrows and corrugations			
Soil groups for irrigation				Available moisture-holding capacity by 1-foot increments of soil depth (inches per foot)	Crop	Depth of root zone to be irrigated (feet)	Net moisture to be replaced each irrigation (inches)	Peak water-use rate (inches per day)	Irrigation frequency for period of peak water-use (days)	Adapted conservation irrigation method†	Basic intake rate sprinkler or furrows or (g. p. m./100 ft.)	Stream size furrows or contour borders or sprinkler (in./hr.)	Est. field eff. %	Gross irr. app. (inches)	Length (feet)	Spacing (inches)
National code No.	Soil map-ping unit No. 1	Representative soil type	Profile description													
1-2-H-1-1	2 79, 78	3 Pascala clay.	4 Heavy textured, deep bottomland soils that have very slow water movement.	5 3.0—1st ft. 2.5—2d ft. 2.0—3d ft.	6 Rice.....	7	8 0.36	9 0.17	10 1	11 Contour levee.....	12 0.008	13 10.5	14 65	15 0.55	16	17
2-H-22	58, 59	Sawmill clay, Sharkey clay.	Heavy textured bottomland soils that are deep and have slow to very slow water movement.	3.0—1st ft. 2.5—2d ft. 2.0—3d ft.	Cotton.....	2.5	2.60	0.25	10	Sprinkler..... Furrow (0.1-0.3%)..... Furrow (0.3-0.5%).....	.35 1.0 .8	.35 50 25	70 60 60	3.7 4.3 4.3	2 660 3 700 3 700	40 40 40
					Corn and soy beans.....	2.5	2.60	.35	7	Sprinkler..... Furrow (0.1-0.3%)..... Furrow (0.3-0.5%).....	.35 1.0 .8	.35 50 25	70 60 60	3.7 4.3 4.3	2 660 3 700 3 700	40 40 40
					Alfalfa, and deep-rooted meadow and pasture.....	3.0	3.00	.35	9	Sprinkler..... Contour borders.....	.40 .35	.40 630	70 80	4.3 3.8	.....	.....
					Shallow rooted meadow and pasture.....	1.5	1.70	.30	6	Sprinkler..... Contour borders.....	.40 .35	.40 630	70 80	2.4 2.1	.....	.....
					Rice.....	.....	.39	.17	1	Contour borders.....	.01	11.3	65	.6	.....	.....
					Shallow rooted truck crops.....	1.0	1.20	.30	4	Sprinkler..... Furrow (0.1-0.3%).....	.35 1.0	.35 35	70 60	1.7 2.0	2 660	36 42
					Medium-rooted truck crops.....	1.5	1.70	.30	6	Furrow (0.3-0.5%)..... Sprinkler..... Furrow (0.1-0.3%).....	.8 .35 1.0	.25 .35 45	60 70 60	2.0 2.4 2.8	625 2 660 2 660	36 42 42
					Deep-rooted truck crops.....	.....	.....	.....	.....	Furrow (0.3-0.5%).....	.8	.25	60	2.8	1 700	36
				
				
				
				
				
				
				
				
				
				
				
				
				
				
				
				
				
				
				
				
				
				
				
				
				
				
				
				
				
				
				
				
				
				
				
				

Shallow-Rooted Truck Crops: Strawberries, onions, lettuce, radishes, spinach, nursery seedlings.
Medium-Rooted Truck Crops: Green beans, tomatoes, carrots, Irish potatoes, cabbage, garden beets,
"cucumbers, nursery transplants.
Deep-Rooted Truck Crops: Asparagus, melons, sweet corn, horse radish, small fruit, sweet potatoes,
! Where subscript "c" follows any soil unit, careful field examination should be made to determine the

possibility of excess water loss by surface irrigation through sand lenses. If excess loss appears possible, the sprinkler method is necessary.

Figure 5.—An example of a portion of a local Conservation Irrigation Guide.

root growth. Since water in the soil does not move freely to the plant roots, the supply within their reach must be periodically replenished to keep the plants growing.

Available moisture

Different soils have different capacities to store water for plant use. After a soil is wet to saturation, a part of the water drains to beyond the reach of plant roots. When this free drainage stops and the soil contains only the water it can hold in the pore space against the force of gravity, the moisture content is said to be at "field capacity." This point is usually reached in from 4 to 48 hours after the rain or irrigation, depending upon the rate of water movement in the soil.

As plants use water from the root zone, the moisture content of the soil drops toward the point that the roots no longer absorb water as fast as the leaves transpire it; then wilting occurs. Crops suffer permanent damage if the moisture level remains at this "wilting point" for an appreciable length of time.

The moisture that plants can withdraw from a soil between its field capacity and its wilting point is known as "available moisture." A soil's capacity to store available moisture is its "available moisture-holding capacity." Available moisture and moisture-holding capacity are measured, like rainfall, in the equivalent of inches depth of water for the surface area.

The available moisture-holding capacities of soils vary primarily with their textures. Coarse sands will store the least available moisture in a certain depth, and clays and mucks will store the most. Available moisture-holding capacity is affected also by other factors, such as organic-matter content, salts, and compaction. In most soils these factors vary with the different horizons of the profile, and the moisture-holding capacities vary accordingly.

Common ranges of available moisture-holding capacities for soils of different textures are as follows:

	<i>Inches of water per foot of soil</i>
Very coarse textures—very coarse sands.....	0.40-0.75
Coarse textures—coarse sands, fine sands, and loamy sands.....	.75-1.00
Moderately coarse textures—sandy loams and fine sandy loams.....	1.00-1.50
Medium textures—very fine sandy loams, loams, and silt loams.....	1.50-2.30
Moderately fine textures—clay loams, silty clay loams, and sandy clay loams.....	1.75-2.50
Fine textures—sandy clays, silty clays, and clays....	1.60-2.50
Peats and mucks.....	2.00-3.00

Detailed information on available moisture-holding capacities for particular soil types can be found in local Conservation Irrigation Guides.

Intake rates

The intake rate is the rate at which water enters the soil. It is dependent upon soil-surface conditions and upon the rate at which the absorbed water can pass through the successive soil layers and make room

for more water to be taken in. The soil layer with the lowest transmission rate, whether at the surface or in the subsoil, sets the limit on the intake rate.

The rate of water absorption is highest at the start of water application; it declines as the soil becomes wet and usually levels off at a near-constant rate set by the most restrictive soil layer through which the water must pass.

Soil texture influences intake rate. Sands usually absorb water most rapidly and fine-textured soils most slowly. Soil conditions, such as structure and organic-matter content, influenced by cultural practices and plant cover, also affect intake rates.

Effective intake rates vary also with the method of water application, i. e., whether by sprinklers, borders, or furrows.

Sprinklers.—Water application by sprinklers is similar to rainfall. The intake rate of a soil is modified by the amount of cover on the land. Bare fields or those with new seedlings or in row crops take in water more slowly than surfaces which have crop cover or mulch.

Furrows.—When irrigation is by furrows, only a part of the soil surface is flooded with water. The amount absorbed is affected by the size of the furrows and the distance between them. The movement of water is both downward and outward from the furrow. This method gives still a different intake rate than either sprinklers or borders.

Borders.—Under the border method of irrigation, the surface of the ground is completely flooded. The soil surface, therefore, has maximum opportunity to take in water, and the rate is not the same as when it is sprayed on with sprinklers or run in furrows.

Intake rates for specific soil types and recommended methods of application can be found in local Conservation Irrigation Guides.

Water movement in soils

Water movement in the soil is affected by the size and arrangement of the pore spaces, which in turn are influenced by the texture and structure of the soil. Pore space is the percentage of volume not occupied by soil particles—that which is occupied by water or air. Coarse-textured gravelly and sandy soils have the least total pore space, although the individual spaces may be larger, and fine-textured clay loams and clays have most pore space.

Soil structure breaks down with excessive tillage or tillage when the soil is wet. A soil so treated is apt to be puddled. Upon wetting and drying, the surface soil bakes into a hard crust that reduces the movement of air in the soil.

Differences in soil profiles may greatly affect the movement of water in saturated soils. Regardless of the intake rate or opportunity for water to enter a soil, limiting factors below the surface, such as a hardpan, claypan, or rock layer, a layer of sand, or a heavy clay subsoil, may restrict the downward movement of water. Therefore, in judging a soil it is necessary to consider the entire profile to the depth of root and water penetration.

The degree of saturation of a soil depends on the rate at which water is applied in comparison to the rate at which it can move downward through the profile. If water is applied no faster than the rate of movement, the soil will be in a firm condition at the end of the irrigation period. This is important when sprinklers are used, for it makes moving the irrigation pipe easier. When water is applied faster than it can soak downward, the top layer remains saturated for some time after the irrigation. This condition makes walking and moving of pipe difficult and creates an erosion hazard should a rain occur immediately after irrigation.

Water Use by Crops

A continuous supply of available moisture in the soil is necessary for the best growth of crops. To be able to maintain this favorable growing condition, the irrigator must know not only how much water his soil will hold but also how fast his crops use moisture and from what depth they withdraw it. The irrigation system must be designed to supply the right amount of water to meet these conditions at the peak of the growing season.

Water-use rates

The water required for optimum growth of a crop includes both that transpired by the plants and that evaporated from the surface of the adjacent soil. This water requirement is commonly called "evapotranspiration" or "consumptive use," and is expressed in inches of water used per unit of time.

The water requirement or water-use rate of a crop varies through the growing season with such things as number of hours of daylight, amount of sunshine, temperature, wind speed, and humidity of the air. Generally, the water requirement is greatest when days are long and sunny, temperature and wind movement are high, humidity is low, and the crop is growing rapidly.

Different crops require different amounts of moisture under the same weather and soil conditions. For example, alfalfa uses more water than most vegetable crops.

For designing an irrigation system, the average daily water-use rate during the 6 to 10 days of most rapid evapotranspiration of the season is sometimes called the "peak use rate." This rate varies from 0.12 to 0.35 inch per day. Peak use rates to be used in irrigation design are given in local Conservation Irrigation Guides.

Moisture-extraction pattern

Plants absorb water mainly through the root hairs and small roots. When conditions are favorable for rapid growth, great numbers of root hairs are formed daily. They move through the small pores in the soil, absorbing water as they contact it. Adequate moisture and air in the soil are favorable for good root development and normal growth.

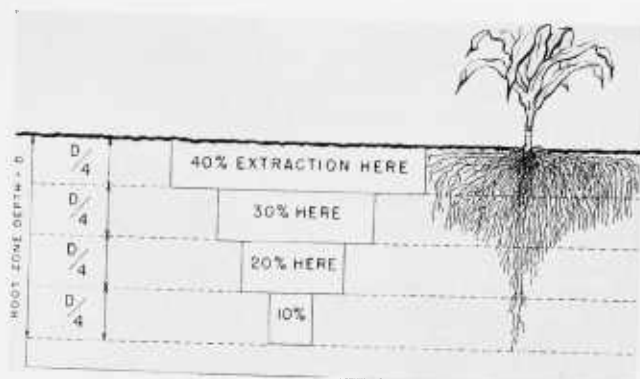


Figure 6.—Average moisture-extraction pattern of plants growing in a soil without restrictive layers and with a constant supply of available moisture.

Only a few plants develop roots and use soil moisture from depths greater than 5 to 6 feet. A good many annual plants and some perennials have root zones of 2 feet or less.

Each kind of plant has its own root-development characteristics, which are inherent in the plant. Most of the feeder roots are located in the upper part of the root zone. In the humid area, a crop usually starts the growing season with the soil at field capacity as a result of spring and winter rains. Therefore, when it becomes necessary to irrigate

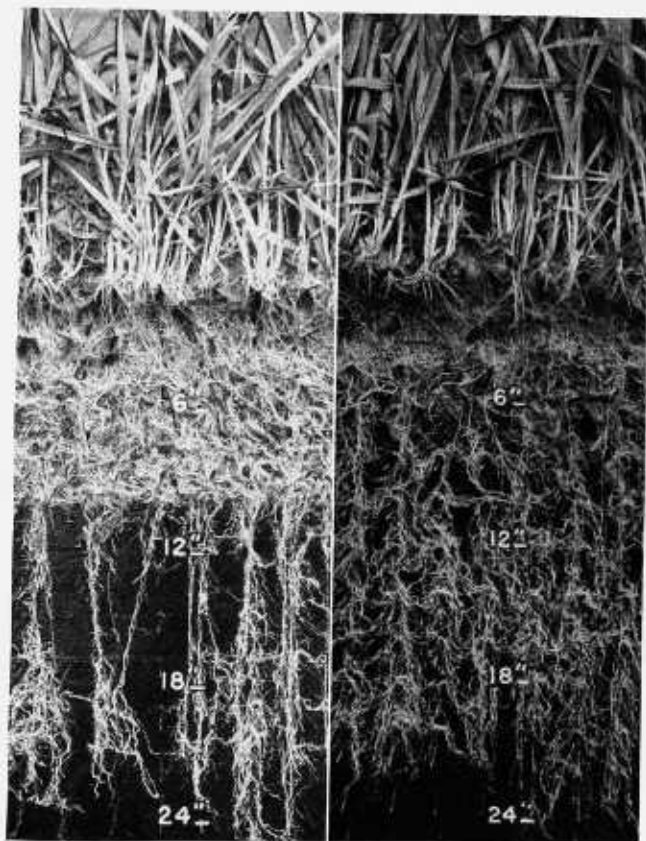


Figure 7.—(Left), roots of oats are confined mainly to the upper 10 inches of a sandy loam soil having a compacted "plowpan;" (right), where the plowpan is broken by deep tillage the roots reach a depth of 24 inches. (Photos courtesy Connecticut Agricultural Experiment Station.)

only the moisture which the plant has extracted from the upper part of the root zone needs to be replaced. The normal moisture-extraction pattern of plants (fig. 6) is a good guide to needed irrigation depths.

Root-growth and moisture-extraction patterns are influenced by effective soil depths (fig. 7). Shallow bedrock, hardpans, and claypans restrict root development. Coarse sands and gravels may hold too little moisture and plant nutrients for normal root growth, or a high water table may stop it. All these things affect the depth of soil that needs to be filled with irrigation water.

Applying Irrigation Water

Irrigation should be planned to apply water before the crop exhausts the available moisture in the root zone. The system needs to be able to apply the right amount of water to the entire field before growth is retarded.

When to start irrigating

Practical considerations determine the moisture level at which to start irrigation. A farmer naturally does not want to start when the soil does not seem dry enough to warrant the trouble and cost of adding more water. As the moisture level drops toward the wilting point, crop growth is retarded and the time left for covering the field before extreme drought damage occurs becomes shorter. To install and operate a system—particularly sprinklers—which will irrigate a field under these conditions is correspondingly costly.

Research shows a marked reduction in crop yields for nearly all crops if the moisture in the root zone falls to less than 20 percent of the total available water-holding capacity. On some soils some crops are affected at the 35- to 40-percent level. The critical level varies with the soil as well as with the crop. The cost in labor and equipment required to maintain high moisture levels in the soil must be carefully balanced against the effect on the yield and quality of the crops involved.

Considering all these factors, it is usually most practical to start irrigation when 50 to 60 percent of the available moisture remains in the root zone. If the irrigation system is properly designed, this starting level allows enough time to cover the area before yields are affected adversely.

Irrigation efficiency

Unfortunately, not all of the water applied during an irrigation enters the soil profile and is held within the root zone for plant use. This is true regardless of the method of application used.

Unavoidable losses are caused by nonuniform distribution of water over the field, waste at the ends of borders and furrows, percolation below root-zone depth, and, with sprinkler irrigation, evaporation from the spray and retention of water on the foliage. Little can be done to reduce evaporation or retention of moisture on the foliage. The other losses can be

held to a minimum by adequate planning, proper design, and efficient operation.

"Field efficiency" of irrigation is the percent of the total volume of water delivered to the field that is stored in the root zone and ultimately consumed by evaporation or transpiration. Other things being equal, efficiency varies with the irrigation method used; for a given method, it varies with the skill exercised in the planning, layout, and operation of the system; with climatic conditions; with the physical properties of the soil; and with other factors. Assuming correct design and installation and reasonably efficient operation, the ranges of efficiency that can be expected from each method of irrigation are as follows:

	Percent
Sprinklers.....	65 to 75
Furrows.....	60 to 70
Contour borders.....	70 to 80
Graded borders.....	65 to 75
Subirrigation.....	Up to 80

Depth to irrigate

Irrigation in the humid area ordinarily does not require wetting the soil at each irrigation to the full depth of the root zone. Because of the normal moisture extraction patterns described earlier (p. 11), moisture content in the upper part of the root zone is reduced to the critical level before the deep moisture is exhausted. Each irrigation is planned to restore the affected zone to field capacity. The depths of needed irrigation for the crops to be grown are an important factor in designing the system.

Recommended irrigation depths for different crops are given in local Conservation Irrigation Guides. Following are usual ranges for common crops on deep, medium-textured, well-drained soils:

	Inches
Corn.....	24 - 36
Cotton.....	24 - 36
Sorghum.....	20 - 30
Small grain.....	18 - 30
Soybeans.....	18 - 36
Alfalfa.....	36 - 42
Pasture.....	18 - 36
Potatoes.....	12 - 24
Tobacco.....	15 - 24
Truck crops:	
Shallow.....	9 - 12
Medium.....	12 - 24
Deep.....	24 - 30
Grapes.....	24 - 30
Fruit trees.....	36 - 60

Irrigation frequency

The frequency of irrigation needed varies according to the water-use rate of the crop and the available moisture-holding capacity of the soil in the root zone. Most frequent irrigations are needed when the crops are transpiring most rapidly. An irrigation system must be designed to meet the demands upon it at this time.

The safe period between irrigations during the time of most rapid evapotranspiration can be calculated by dividing the amount of water to be replaced at each irrigation by the peak use rate of the crop. This gives the maximum number of days that can

be used to cover the irrigated area during the periods of peak water use. It is also the minimum number of days after starting irrigation before the crop will need to be irrigated again if no rain falls in the meantime. The irrigation system, therefore, needs to be designed so that all the area can be irrigated in this number of days.

Recommended irrigation frequencies for different crops on different soils are shown in local Conservation Irrigation Guides.

Amount to apply

The amount of water applied at any particular irrigation should be the amount required to bring the moisture level in the soil up to field capacity plus the amount required to overcome the unavoidable losses discussed under Irrigation Efficiency. This amount is usually expressed in inches of depth on the area irrigated. It can be calculated by dividing the amount of water to be replaced in the depth to be irrigated by the estimated irrigation efficiency expressed as a decimal.

For example, if the amount of water required to refill the soil profile is 1.8 inches, and the irrigation efficiency is 70 percent, the total depth of water to be applied would be $1.8/0.70$ or 2.6 inches.

In determining the amount of water to apply at any time, the irrigator must first estimate or measure the amount of available moisture in the soil to the depth of irrigation. The difference between this amount and the total available moisture-holding capacity of the soil to this depth is the amount to be replaced by irrigation.

Determining soil moisture

Moisture content of the soil can be either measured or estimated by one of the following methods:

Soil sampling.—Soil samples are taken from the desired depths at several locations in each soil type, weighed, dried in an oven, and then weighed again. The difference in weight is the amount of moisture in the soil, which can be converted to a percentage or to inches of water remaining in the profile.

This method is the most accurate, but is not generally practical for farm use. Its accuracy depends on the number of samples taken and the skill exercised in mixing and handling them. It requires the use of facilities not ordinarily owned by farmers and involves much time and labor. It is used primarily in experimental work and is a standard against which other methods of moisture determination are compared.

Measuring instruments.—A variety of instruments for measuring soil moisture are available commercially. These devices may not be as accurate as the sampling and drying procedure, but they are being improved. Their use can result in more efficient water application which will more than pay for them by increasing yields and saving water and labor. The instruments now available are of two general types: (1) tensiometers and (2) electrical conductivity-measuring devices.

The tensiometer consists of a porous cup filled with

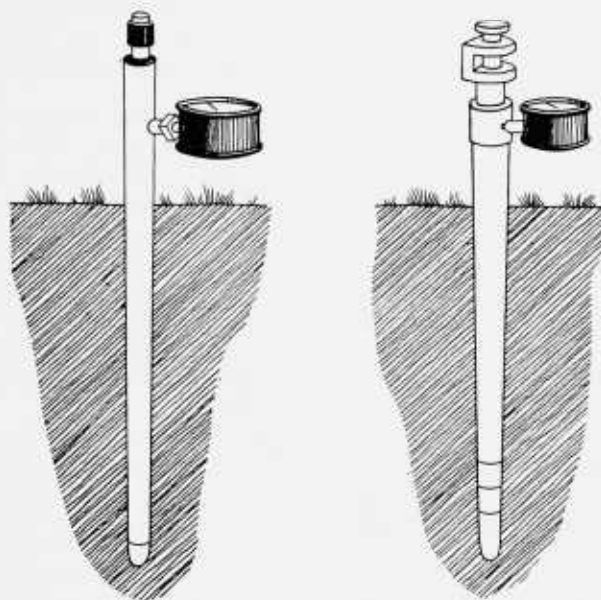


Figure 8.—Tensiometers for measuring soil moisture.

water and connected by a continuous water column to a vacuum measuring device, either a gage or manometer (fig. 8). The cup is placed in the soil at the desired depth, and measurements are read above ground on the vacuum indicator. These instruments measure soil-moisture tension directly. A moisture characteristic curve for each soil is needed to convert moisture-tension measurements into available moisture percentages.

At present, tensiometers do not satisfactorily measure the entire range of available moisture in all soil types. They are satisfactory for sandy soils where tensions are low, but they are not so well adapted to clay soils where tensions normally are high. They are simple to operate and require a minimum of labor.

Electrical instruments (fig. 9) use the principle

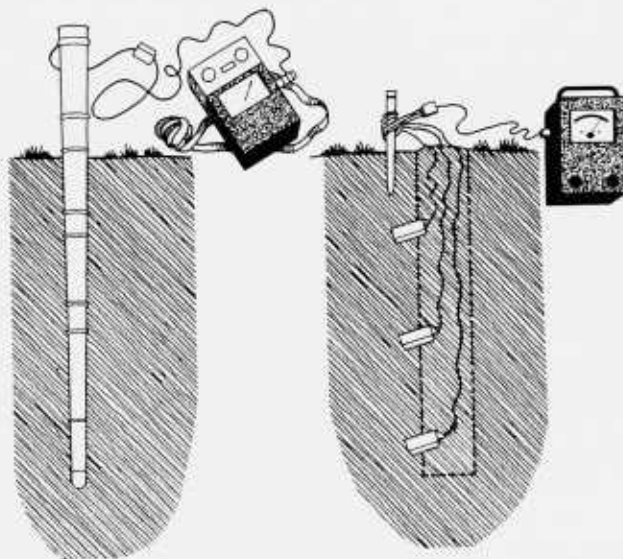


Figure 9.—Electrical-conductance meters.

that a change in moisture content produces a change in some electrical property of the soil or of an instrument in the soil. Usually this property is electrical conductivity.

Electrodes permanently mounted in conductivity units—usually blocks of plaster of paris, nylon, fiberglas, or gypsum—are buried at the depths to be studied. Resistance or conductance meters measure the changes in electrical resistance in the blocks associated with changes in the moisture content of the soil. Under usual conditions these instruments can give good indications of moisture content, if used according to manufacturers' instructions. For really accurate measurements, the blocks need to be calibrated in the field.

Moisture accounting.—Calculated water-use data can be used to maintain a daily "inventory" of the moisture remaining in the soil. The "bookkeeping" starts when the moisture is known to be at or very near field capacity. Each day the amount of water used is subtracted from the total available moisture in the profile. When the balance reaches a predetermined level, usually 50 to 60 percent of the total, time to start irrigation is indicated.

The total available moisture-holding capacity of the soil is taken from local Conservation Irrigation Guides. Average daily water use is computed from climatological data for monthly periods. These daily averages must be adjusted as temperature, humidity, sunshine, and wind velocity vary from normal. The effective rainfall must also be measured as it occurs and added to the daily balance.

This procedure has the obvious advantage of requiring no equipment or labor. Its accuracy depends, first, on the accuracy of the computed daily water-use rates and, second, on the irrigator's

judgment in adjusting these rates for variations in the climatological factors.

The "feel" test.—The feel and appearance of soil samples as taken in the field indicate the available moisture content. The samples are compared with the descriptions in table 1 and the soil-moisture content estimated by this guide. Obviously, this is not an accurate method but with experience and judgment the irrigator should be able to estimate the moisture level within 10 to 15 percent of actual.

Water Supplies

Before investing in an irrigation system, a farmer should assure himself that he has a water supply that is (1) adequate to meet the requirements of the acreage of crops to be irrigated, (2) of suitable quality, (3) dependable, (4) economically accessible, and (5) legally available. These points should be carefully investigated, whether the water is to come from a perennial stream, a reservoir or lake, or ground water.

Amount of Water Needed

Whatever the source of water, it must be able to deliver an irrigation stream large enough to cover the irrigated area in the allotted interval. Or, conversely, the size of irrigated area should be limited to what can be adequately irrigated by the available irrigation stream.

The rate of dependable flow required depends on the size of the area irrigated, the moisture requirements of the crops during periods of peak use, the efficiency of the distribution system on the farm, and the time allotted for one irrigation.

TABLE 1.—Guide for judging how much moisture is available for crops

Soil moisture remaining	Feel or appearance of soil			
	Coarse-textured soils	Moderately coarse-textured soils	Medium-textured soils	Moderately fine- and fine-textured soils
0 percent.....	Dry, loose single grained; flows through fingers.	Dry, loose, flows through fingers.	Powdery dry; sometimes slightly crusted but easily broken down into powdery condition.	Hard, baked, cracked; sometimes has loose crumbs on surface.
50 percent or less.....	Appears to be dry; will not form a ball with pressure. ¹	Appears to be dry; will not form a ball. ¹	Somewhat crumbly but holds together from pressure.	Somewhat pliable; will ball under pressure. ¹
50 to 75 percent.....	Same as very light texture with 50 percent or less moisture.	Tends to ball under pressure but seldom holds together.	Forms a ball, somewhat plastic; will sometimes slick slightly with pressure.	Forms a ball; ribbons out between thumb and forefinger.
75 percent to field capacity (100 percent).	Tends to stick together slightly; sometimes forms a very weak ball under pressure.	Forms weak ball; breaks easily; will not slick.	Forms a ball; is very pliable; slicks readily if relatively high in clay.	Easily ribbons out between fingers; has slick feeling.
At field capacity (100 percent).	Upon squeezing no free water appears on soil but wet outline of ball is left on hand.	Same as coarse-textured soils.	Same as coarse-textured soils.	Same as coarse-textured soils.

¹ Ball is formed by squeezing a handful of soil very firmly.

This required rate can be determined by the formula,

$$Q = \frac{453 AD}{FH}$$

Where:

Q = the required flow in g. p. m.

A = the irrigated area in acres

D = the gross depth of application in inches

F = the days required to complete one irrigation

H = the actual operating hours per day

Where losses occur in the water-distribution system, this required flow, Q , must be increased to the extent of these losses. There will be no losses in pipelines, and only slight ones in lined canals, but the losses in unlined canals may be large.

Most farmers in humid areas prefer to irrigate only in daylight. This requires a greater rate of flow to irrigate a certain area than if the system operated 24 hours a day.

For example, if a farmer wants to apply 2.4 inches of water on a 40-acre field in 6 days, irrigating 12 hours a day, the required rate of flow would be computed as follows:

$$Q = \frac{453 \times 40 \text{ acres} \times 2.4 \text{ inches}}{6 \text{ days} \times 12 \text{ hours}} = 604 \text{ g. p. m.}$$

Irrigating 24 hours per day, the required rate of flow would be only 300 g. p. m.

Sources of Supply

Water for irrigation in humid areas nearly always comes from a source developed on the farm. There are few organized group enterprises, such as are common in the West. The individual farmer generally must seek his irrigation water from perennial streams, lakes or reservoirs, or wells on his own land.

Perennial streams

Farms adjoining streams can often use them as a source of irrigation water. Since streams in the humid areas depend almost entirely on rainfall, their rates of flow are likely to vary during the year. The supply of water is lowest during long dry periods when irrigation needs are greatest. If the acreage to be irrigated requires more water than the dry-weather flow, the stream is not an adequate source unless its water can be stored in a reservoir. The smaller perennial streams and intermittent streams are not dependable supplies except in conjunction with storage structures.

Sometimes the farmer can increase the area irrigated by storing the overnight flow in an excavated pit or reservoir. The reservoir should be large enough to store the additional water needed to keep the system operating the next day.

Unless the stream is large enough that the adequacy of the supply is obvious, the irrigator needs to determine the dependable dry-weather flow. He can first check to see if the stream has been gaged by the U. S. Geological Survey or some other Federal or State agency. If not, it will be necessary to measure the flow during a prolonged dry period.

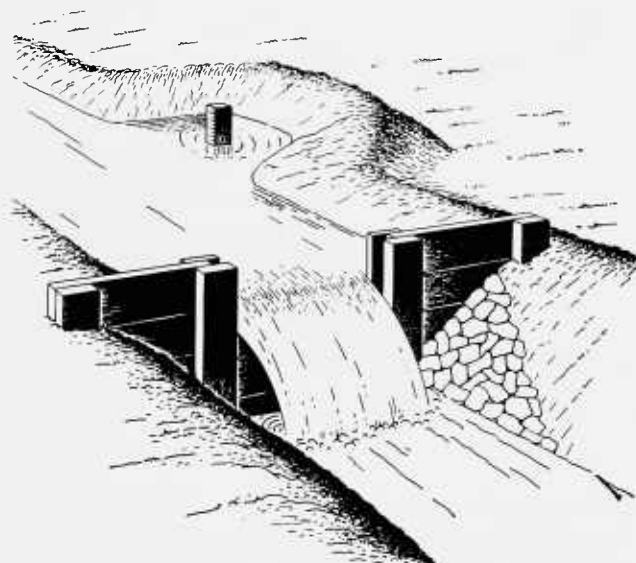


Figure 10.—Rectangular weir.

Measuring water in streams.—Two common devices for measuring small streams of water are the rectangular weir and the Parshall flume. The weir is the simplest device and under standard conditions is very accurate. The Parshall flume is often more convenient to use and is satisfactory for planning irrigation. Detailed information on the construction and use of these devices is available in U. S. Department of Agriculture Circular 843, *Measuring Water in Irrigation Channels With Parshall Flumes and Small Weirs*.

The rectangular weir (fig. 10) commonly consists of a bulkhead of timber, concrete, or metal across the stream channel, having in its top edge a rectangular opening through which the stream flows. This opening is called the weir notch; its bottom edge is the crest; and the depth of water passing over the crest, as measured at a definite point upstream from the bulkhead, is the head.

The weir is installed so the notch is as near the center of the stream as possible. The size of the notch should be such as to cause the water to pond above the weir and approach at a low velocity. The water surface below the bulkhead must be low enough that air moves freely below the stream as it leaves the notch. A head of 0.1 foot over the weir is usually enough to permit the stream to clear the downstream edges of the crest and sides.

The depth of water, or head, as measured on a scale above the crest, indicates the volume of water passing over the weir. These amounts are read from weir-discharge tables for different length notches available in Circular 843.

The Parshall flume (fig. 11) is an excellent device for measuring the flow in small streams. It can be constructed of wood, sheet metal, or concrete, and in a wide variety of sizes. The smaller sizes of metal are portable.

The flume consists of a converging section, a throat, and a diverging section. Two depth gages on the side of the flume are set with the zero points

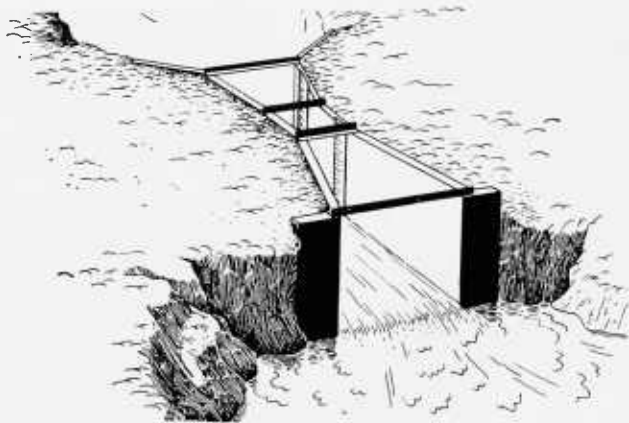


Figure 11.—Parshall measuring flume.

even with the crest of the flume. The depth of flow is read from these gages and the corresponding rates of flow are read from tables in Circular 843.

A Parshall flume does not require as much ponding as a weir for satisfactory results. Another advantage is its ability to operate as a single-head device with a minimum loss of head. When both a flume and weir of equal crest length are operating under free flow at the same discharge, the loss of head for the flume is only about one-fourth as much as for the weir.

Quality of water.—The quality of water in streams in the humid areas is generally satisfactory for irrigation. Some streams may be polluted with industrial wastes harmful to plants. If there is any question on this point, samples of the water should be analyzed.

Water at the mouths of streams along the Atlantic and Gulf coasts affected by tides often contains enough harmful salts to make it unfit for irrigation. Automatic tide gates can be installed in the smaller streams to control the influx of tidewater. The gates are opened to permit the flow of fresh water at low tide and closed to keep out sea water at high tide. Some farmers use tidal streams by irrigating only during periods of low tide when fresh water is running in them. In any event, the tidal streams should be used for irrigation only after chemical analyses have shown that their waters are safe.

Legal rights.—In most humid States the rights of farmers to use water from streams are governed by the riparian doctrine. Under the rules of common law, a riparian owner is entitled to have the stream

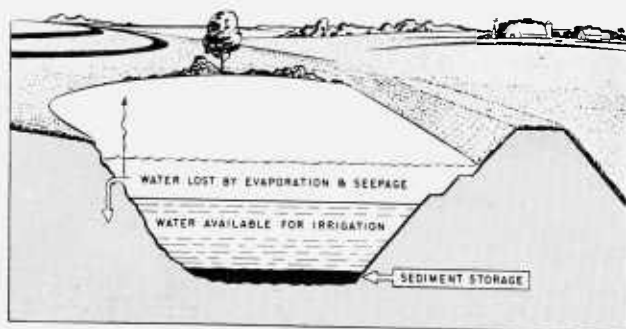


Figure 12.—Cross section of a typical farm irrigation reservoir.

flow through or past his land undiminished in quantity and unimpaired in quality except for domestic use by other riparian owners. In many States the courts have not determined whether irrigation is a "domestic" use; in these States the farmer's right to use water for irrigation is in doubt. Where such doubt exists, the farmer should obtain legal counsel before investing in an irrigation system.

Reservoirs and lakes

Storage reservoirs are increasing in popularity as sources of irrigation water. Many farms have no other dependable source.

Impounding structures.—Irrigation reservoirs usually are of the impounding type created by building an earth dam across an intermittent or spring-fed stream. Water is usually impounded from drainage areas of 50 to 2,000 acres by dams 10 to 30 feet high; the reservoirs hold 10 to 300 acre-feet of water. A reservoir should be located as near as possible to the irrigated field.

The acreage of crops irrigated from a farm reservoir is limited by the amount of water that will be available during drought periods when irrigation is needed. The required storage capacity of a reservoir is determined from the maximum seasonal requirements of the crops to be irrigated, the effective rainfall expected in the growing season, the application efficiency of the method of irrigation, the unavoidable losses due to seepage and evaporation, and the volume of dry-weather streamflow, if any. An allowance for anticipated sedimentation in the reservoir should usually be made. Figure 12 shows a cross section of a typical farm irrigation reservoir illustrating the capacity needed to overcome losses as well as that required to meet the seasonal requirements of the crops.

The capacity of a reservoir is measured in acre-feet, which is the product of the surface area in acres and the average depth in feet. For estimating capacity of an impounding reservoir, four-tenths of the maximum depth at the dam can be used as the average depth. More precise results can be obtained by taking cross sections of the reservoir with surveying instruments.

The watershed area above the reservoir must be large enough that the storm runoff or reservoir inflow is adequate to replenish the water supply as needed. Major storm runoff usually occurs about twice each year. The amount of runoff that can be expected annually from a watershed depends on many factors that vary widely over the humid area. Engineering knowledge is needed to evaluate these factors for a watershed and estimate the expected annual runoff. It is often possible, however, to judge the adequacy of a contributing watershed by studying nearby reservoirs with similar areas.

Sometimes the water supply from a small watershed can be augmented by off-channel storage in a reservoir where water can be pumped or diverted from a nearby stream during rainy seasons.

The cost of storing water in an impounding-type

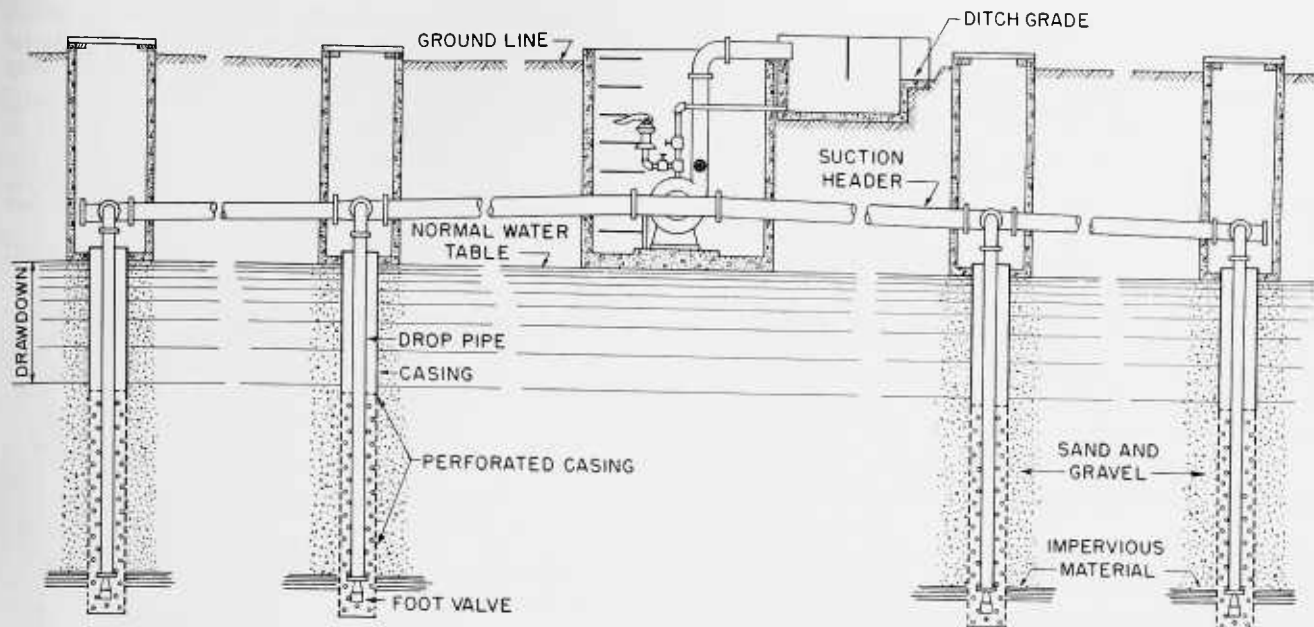


Figure 13.—A battery of four shallow wells.

reservoir depends mostly on the topography of the site but also on the character of foundation and embankment material, the need for toe drainage, and other factors. A study of a number of reservoirs in the Southeast indicated that the cost of providing storage for 1 acre-foot of water ranged from \$70 to \$120.

The water in farm reservoirs usually is suitable for irrigation. In some areas where tobacco is grown, the runoff water may carry a crop disease to the reservoir from where it may be spread to the crop through the irrigation system.

The farmer's right to impound surface runoff for irrigation ordinarily is not questioned if he owns the entire watershed area. He may impound runoff from land owned by others only if he does not damage owners below him by depriving them of their riparian rights to the water. In most humid States a permit to impound water must be obtained from a State or county agency.

Excavated reservoirs.—Excavated reservoirs are an important source of irrigation water in some localities. The storage basin is usually excavated in a low-lying level area where the lateral movement of water underground replenishes the supply. Thus, there are two essential conditions for a dependable excavated reservoir: (1) A high natural water table under adjacent lands, and (2) a highly pervious layer permitting the rapid lateral movement of water within practical excavation depths, usually 12 to 20 feet.

The foregoing requirements and economic considerations limit the use of excavated reservoirs to the irrigation of small areas, usually not exceeding 10 to 15 acres. The cost of these ranges from about \$200 each, up to \$250 per acre-foot of storage provided.

Natural lakes.—In Florida many natural lakes are used for the irrigation of citrus crops and occasionally for vegetables. Lakes usually furnish a

desirable quality of water. Their capacity often restricts the acreage that can be irrigated. Many of the same problems involved in using farm reservoirs also pertain to lakes.

Ground water

Many farms in humid areas do not touch perennial streams and do not contain suitable sites for the construction of storage reservoirs. For them, ground water is the only prospective source of supply.

In many areas large quantities of water are stored beneath the earth's surface in layers of saturated sand and gravel. Not all this water can be recovered, nor is it always near enough to the surface for economic pumping. Where conditions are favorable, however, ground water may be the most dependable source of irrigation water.

Information on where and in what quantity ground water is available can usually be obtained from the State Geologist, the U. S. Geological Survey, or from local well drillers.

Deep wells.—Deep wells are generally the most dependable sources of supply. They are usually drilled into a deep water-bearing stratum. The type of pump required depends upon the depth to the water level. Most deep wells require turbine pumps, but where pressure causes the water to rise to within a few feet of the surface a centrifugal pump can be used.

The cost of a deep-well installation depends upon the size and depth of hole and the type of pumping equipment required to obtain the desired rate of flow. Cost estimates can best be obtained from reliable well-drilling firms with experience in the locality.

Shallow wells.—In some localities water can be obtained near the surface from shallow water-bearing strata. Often these strata give low yields and a battery of wells is needed to provide the required flow of water (fig. 13).

There are several types of shallow wells; drilled

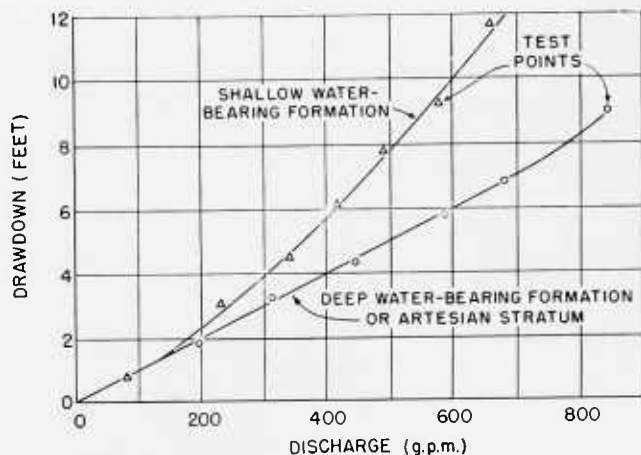


Figure 14.—Drawdown-discharge curves for two types of aquifers.

and driven-point wells are most common. The drilled well generally is more expensive but is better suited for an irrigation system because it yields more water.

Measuring well discharge.—The first question to be answered about a well for irrigation is whether it will deliver a dependable supply of water at a rate fast enough to meet the needs of the area to be irrigated (p. 14).

If the irrigation system is operated in daylight only, the well can be made to serve a larger area by pumping continuously and storing the overnight flow in a small excavated reservoir.

A well should be thoroughly tested before additional money is invested in an irrigation system. The test consists of pumping the well at various rates and measuring the "drawdown" in the well at each discharge rate. By plotting the drawdown against discharge a curve (fig. 14) is obtained which shows the well's performance under several different conditions. This information is of prime importance in (1) deciding the size of the area that can be irrigated, (2) selecting a pump to fit the well, and (3) selecting a power unit to drive the pump.

The drawdown in shallow open wells can often be measured by lowering a tape into the well until it touches the water. The distance the water level drops from its position prior to starting the pump is the extent of drawdown at any particular time.

For deeper wells, an electric drawdown gage (fig. 15) can be used. The measuring line is lowered between the pump column and well casing, and a light or an ammeter shows when the electrode at the end of the measuring line touches the water.

Another method of checking water levels is with an air-line and pressure gage installed with the pump (fig. 15). A small air pump, such as a tire pump or spray rig, is attached to the air line and the pounds of pressure required to force the water out of the submerged pipe multiplied by 2.31 tells the number of feet the pipe is under water. This figure subtracted from the length of the air line below ground surface shows the water level.

A simple way to estimate the flow from a well is to use a carpenter's square to measure the horizontal and vertical proportions (dimensions X and Y of fig. 16) of the arc of the stream from a horizontal pipe flowing full. If the fall of water is sufficient to obtain a vertical measurement of 12 inches, the corresponding rate of discharge can be read directly

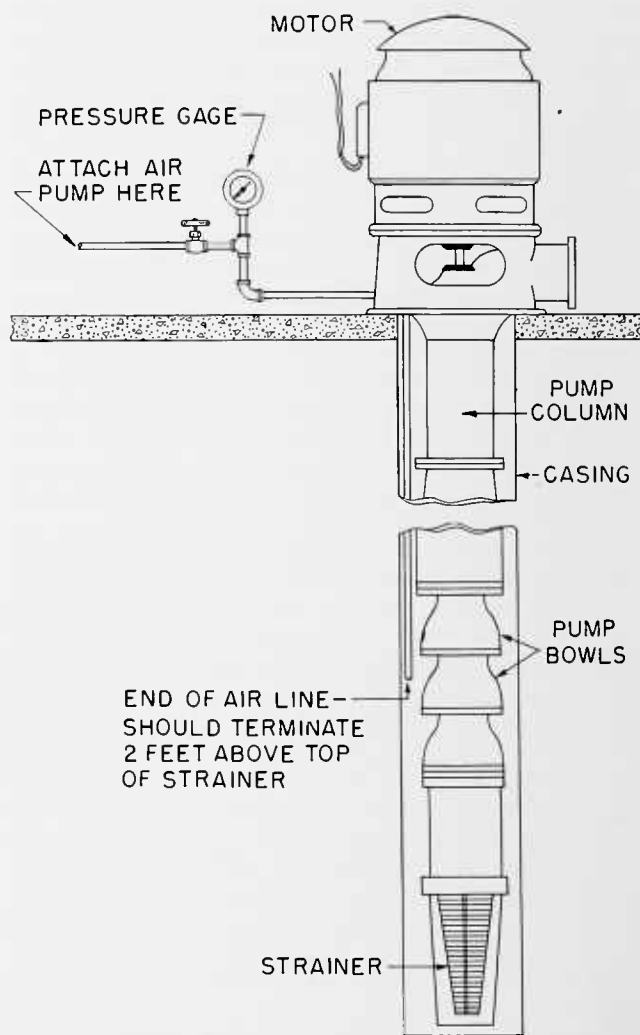
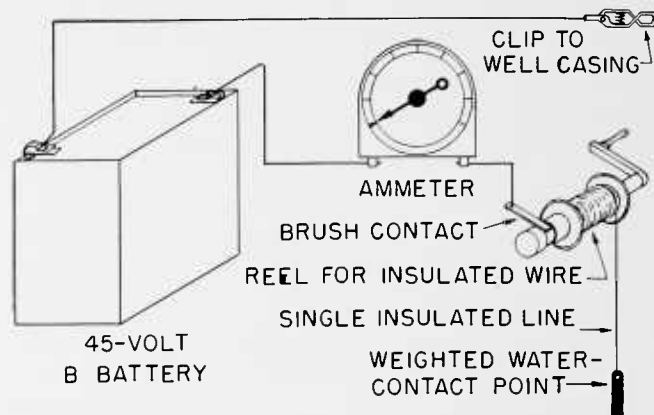


Figure 15.—Two types of drawdown gages: (Top), electrical-contact gage; (bottom), air-line gage.

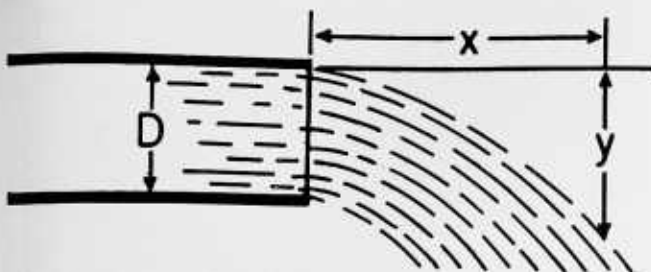


Figure 16.—Flow from horizontal pipe. Dimensions to be used in calculating discharge are: *D*, diameter of pipe; *X*, horizontal distance; and *Y*, vertical distance.

from table 2. Or, the discharge can be calculated from the following equation:

$$Q = \frac{2.83 D^2 X}{\sqrt{Y}}$$

Where

- Q*=gallons per minute
- D*=diameter of pipe in inches
- X*=horizontal distance in inches
- Y*=vertical distance in inches

Where it is inconvenient to use this method, the discharge from a well can be turned into a ditch and measured with a rectangular weir or a Parshall flume as previously described.

Commercial flow meters usually give accurate measurements, but these meters are expensive and are usually not readily available in the humid States.

Quality of water.—Ground water in the humid States is generally suitable for irrigation. Near the Atlantic and Gulf coasts, however, salt has seeped into many aquifers to the extent that the waters are harmful to crops. If there is any question about the quality of well water, it should be tested before use.

Legal rights.—The rights of a farmer to the use of ground water for irrigation are not clearly defined in most Eastern States. In many States the rule of "reasonable use" applies to ground water, and this water may be used for irrigation only if there is no adverse effect on other users. In some States and in many local subdivisions, a permit is required to develop ground-water supplies.

Pumps and Power Units

The pump and power units are a major part of the cost of an irrigation system. The amount of money

that can profitably be spent for this equipment depends on the value of the crops to be produced and the number of hours the pump will operate each season. If it is to be used only a short period each year, an expensive unit involving high fixed costs may not be economical. Cheaper pumps are usually lower in efficiency and consequently require more power but for short periods of operation this may be more than offset by the lower first cost.

Specifications of pumps and power units are based in part on the "head" or pounds of pressure which must be overcome to move the water at the desired rate. The elements of a pumping plant and of the total head involved are diagramed in figure 17. To convert head in feet to pressure in pounds per square inch, multiply head by 2.3; to convert pressure to head, multiply pressure by 0.433 (fig. 18).

Pumps

Centrifugal, turbine, propeller, and mixed-flow pumps are commonly used for irrigation pumping. Each type of pump is adapted to a certain set of conditions under which it will give efficient service.

Centrifugal pumps.—Centrifugal pumps (fig. 19) usually operate efficiently when pumping against total heads of more than 12 feet. The suction lift should not exceed 18 feet at sea level or 17 feet at 2,000 feet elevation. These pumps operate most efficiently at all elevations if the suction lift is less than 15 feet.

Centrifugal pumps are well adapted to most sprinkler irrigation work since the total head requirements are usually high enough to produce good efficiencies. For example, a sprinkler system operating at 50 pounds pressure would require a pump to operate against a total head in excess of 115 feet.

Because of their low first cost, light weight, long life, ease of operation, and high efficiency, horizontal centrifugal pumps are widely used for irrigation pumping. They are well adapted to pumping from shallow wells, pits, reservoirs, streams, and ditches. However, where the water level fluctuates widely they cannot be used without raising and lowering the pump.

Turbine pumps.—Deep-well turbine pumps (fig. 20) are adapted primarily for use in cased wells where the water surface is too deep for a centrifugal pump. They have been used successfully to pump from 500 feet below ground. Turbine pumps are as efficient as good horizontal centrifugal pumps.

TABLE 2.—Flow from horizontal pipes flowing full
[$Q=0.818 D^2 X$ when $Y=12$ inches]

Pipe diameter (<i>D</i>) (inches)	Measured distance (<i>X</i>) in inches (<i>Y</i> =12 inches)										
	12	14	15	18	20	22	24	26	28	30	32
2.....	<i>G. p. m.</i> 39	<i>G. p. m.</i> 46	<i>G. p. m.</i> 52	<i>G. p. m.</i> 59	<i>G. p. m.</i> 66	<i>G. p. m.</i> 72	<i>G. p. m.</i> 78	<i>G. p. m.</i> 85	<i>G. p. m.</i> 91	<i>G. p. m.</i> 98	<i>G. p. m.</i> 104
4.....	157	183	204	235	261	288	314	340	366	392	418
6.....	354	414	472	530	590	650	708	767	825	885	945
8.....	627	731	836	940	1,048	1,150	1,252	1,360	1,460	1,570	1,670
10.....	980	1,145	1,308	1,470	1,635	1,800	1,960	2,120	2,285	2,445	2,620
12.....	1,413	1,650	1,880	2,120	2,360	2,580	2,820	3,061	3,300	3,520	3,760

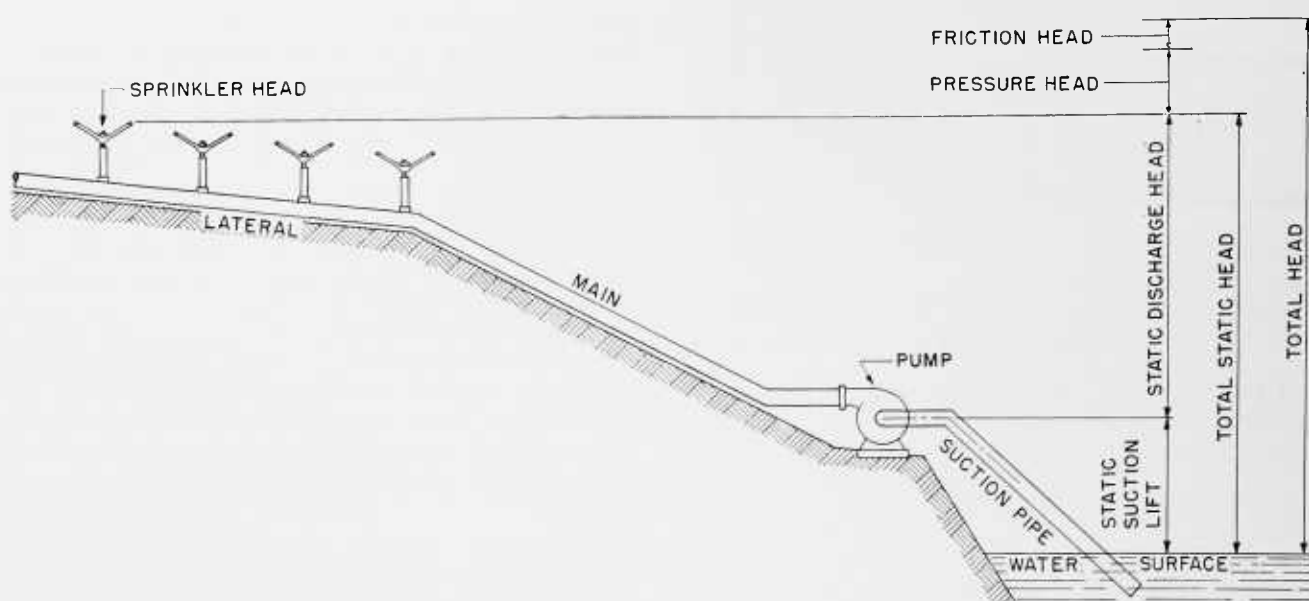


Figure 17.—Elements of a pump and power unit on a sprinkler system and the corresponding elements of “total head” used in calculating power requirements.

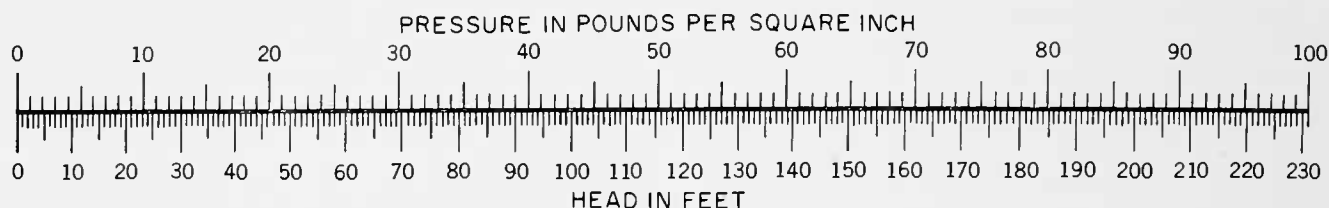


Figure 18.—Scale for converting units of head and pressure.

They will give long and dependable service if properly installed and maintained. They are usually more expensive than centrifugal pumps and are more difficult to inspect and repair.

Propeller pumps.—Propeller pumps are useful for pumping against heads of less than 10 feet. The water is moved by the lift of the blades on the impeller. These pumps will deliver large streams of water under low heads. They are well adapted to surface irrigation and to drainage. The first cost is generally less than that for other types of pumps. Propeller pumps deliver more water than centrifugal pumps for a given size impeller and provide a more nearly constant flow with changing pumping lift.

Mixed-flow pumps.—Mixed-flow pumps operate efficiently at low heads of about 6 to 26 feet. The impeller on a mixed-flow pump is a combination structurally of the propeller and centrifugal types. They pump best against heads intermediate between those recommended for propeller and centrifugal pumps, preferably 10 to 16 feet. They are best adapted to deliver large streams of water.

Power units

The power required to pump water depends on (1) the quantity of water, (2) the total head or pressure against which it is pumped, and (3) the efficiency of the pump.

Size of power unit.—Table 3 shows the horsepower required to pump different quantities of water against total heads ranging from 10 to 240 feet.

This table is computed on the assumption that the plant efficiency is 50 percent and it should be used for preliminary estimates only.

Where the actual pump efficiency is known, the horsepower requirement can be computed by the following formula:

$$\text{B. Hp.} = \frac{\text{g. p. m.} \times \text{total head}}{3,960 \times \text{efficiency}}$$

Where:

B. Hp.=brake horsepower required

g. p. m.=gallons per minute to be pumped

total head = static head + friction losses + pressure head, in feet

efficiency = efficiency of pump expressed as a decimal

If a water-cooled gasoline engine is used, multiply the result by 1.45; if an air-cooled engine, by 1.6; or if a diesel engine, by 1.25.

Types of power units.—Many types of power units can be used for operating pumps. An old automobile engine belted to the pump may do the job at low original cost, but operating cost is likely to be high and service unreliable. Money is often wasted by investing in old inefficient engines not suited to the job.

It must be remembered that a farm tractor used to furnish power will not be available for other farming operations and may require modification of the cooling system. Farm tractors are not built for continuous operation such as is needed to power an irri-



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Figure 19.—A centrifugal pump.



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Figure 20.—A deep-well turbine pump powered by an electric motor.

gation pump. If a tractor is used, it should be large enough so that it is not necessary to operate the engine at full throttle. Also, the motor should be equipped with safety devices.

Where available at reasonable rates, electricity is usually the most satisfactory source of power for irrigation pumping. Electric motors offer high efficiency, reliability, compactness, and low cost of upkeep, which makes them especially desirable for operating pumping plants.

Internal combustion engines are most widely used where electric power is not available or where it is too expensive. These include gasoline and diesel engines. The former type may be adapted to burn natural gas, kerosene, or distillates. Proper cooling is very important when internal combustion engines are used for irrigation pumping.

Gasoline engines cost less initially than diesel engines and are better adapted to smaller loads and shorter operating hours. Diesel engines are best for heavy duty and generally give longer service. The choice of an internal combustion engine for a given job depends on the size of load, length of operating periods, and the required life of the engine.

Irrigation pumping plants often operate for long periods without attention. For this reason power units should be equipped with safety devices to shut them off when changes in operating conditions occur that might cause damage. Such changes include when: (1) Oil pressure drops, (2) coolant temperature becomes excessive, (3) pump loses its prime, or (4) the discharge pressure head drops.

TABLE 3.—Power required to pump different quantities of water against different heads with pumping plant of 50-percent efficiency¹

Discharge		Total head—																	
(G. p. m.)	(C. f. s.)	10 feet	20 feet	30 feet	40 feet	50 feet	60 feet	70 feet	80 feet	90 feet	100 feet	120 feet	140 feet	160 feet	180 feet	200 feet	220 feet	240 feet	
		Horse-power	Horse-power	Horse-power	Horse-power	Horse-power	Horse-power	Horse-power	Horse-power	Horse-power	Horse-power	Horse-power	Horse-power	Horse-power	Horse-power	Horse-power	Horse-power	Horse-power	
25.....	0.06	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{3}$	$\frac{1}{2}$	$\frac{2}{3}$	$\frac{3}{4}$	1	1	1	1	2	2	2	2	3	3	3	
50.....	.11	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{2}$	1	1	2	2	2	2	3	3	4	4	5	5	6	6	
100.....	.22	$\frac{1}{2}$	1	2	2	3	3	4	4	5	5	6	7	8	9	10	11	12	
150.....	.33	$\frac{3}{4}$	2	2	3	4	5	5	6	7	8	9	11	12	14	15	17	18	
200.....	.45	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20	22	24	
250.....	.56	1	3	4	5	6	8	9	10	11	13	15	18	20	23	25	28	30	
300.....	.67	2	3	5	6	8	9	11	12	14	15	18	21	24	27	30	33	36	
350.....	.78	2	4	5	7	9	11	12	14	16	18	21	25	28	32	35	39	42	
400.....	.89	2	4	6	8	10	12	14	16	18	20	24	28	32	36	40	44	48	
450.....	1.00	2	5	7	9	11	14	16	18	20	23	27	32	36	41	45	50	54	
500.....	1.11	2	5	8	10	13	15	18	20	23	25	30	35	40	45	50	55	60	
600.....	1.34	3	6	9	12	15	18	21	24	27	30	36	42	48	55	61	67	73	
700.....	1.56	4	7	11	14	18	21	25	28	32	35	42	50	57	64	71	78	85	
800.....	1.78	4	8	12	16	20	24	28	32	36	40	48	57	65	73	81	89	97	
900.....	2.01	5	9	14	18	23	27	32	36	41	45	55	64	73	82	91	100	109	
1,000.....	2.23	5	10	15	20	25	30	35	40	45	51	60	71	80	91	101	111	121	
1,250.....	2.78	6	13	19	25	32	38	44	50	57	63	76	88	101	114	126	139	151	
1,500.....	3.34	8	15	23	30	38	45	53	60	68	76	90	106	121	136	151	166	181	

¹ Adapted from U. S. Dept. Agr. Farmers' Bul. 1857, Small Irrigation Pumping Plants.

Sprinkler Irrigation

In sprinkler irrigation the water is sprayed into the air and allowed to fall on the land surface in a uniform pattern at a rate less than the intake rate of the soil.

The use of sprinklers for applying irrigation water began in the United States about 1900. The introduction of light-weight aluminum pipe and quick couplers after World War II reduced the labor cost of moving portable sprinkler equipment. More economical and dependable power plants also helped make sprinkler irrigation more acceptable to farmers. Consequently, this method of irrigation has spread rapidly during recent years.

Some advantages of the sprinkler method are:

- (1) It is adapted to most soils that can be irrigated and is particularly adapted to sandy soils.
- (2) It can be used for all major farm crops, except rice.
- (3) It is adapted to both level land and steep slopes; necessary erosion-control measures on steep land can be used with sprinkler irrigation.
- (4) It requires little or no land leveling if surface drainage is adequate. This point is of particular importance on shallow soils where leveling would expose large areas of infertile subsoil.
- (5) Very light applications for new seedlings and small plants can be made efficiently.
- (6) Farming operations are not hindered by field ditches and dikes.
- (7) Small streams of water can be more efficiently used.
- (8) Soluble fertilizer can be applied and controlled economically and efficiently.
- (9) Frost can be controlled on certain fruit and truck crops.
- (10) Most of the equipment can be moved from field to field.

Some limitations are:

- (1) It usually requires the highest initial investment of any system, except where extensive land leveling is necessary for surface or subirrigation.
- (2) Wind can cause uneven water distribution.
- (3) Power requirements are high because of the high pressures required to operate sprinklers.
- (4) Water must be relatively free of sand and debris.
- (5) Water cannot be applied efficiently at low rates under hot, windy conditions.

Types of Systems

There are three general types of sprinkler irrigation systems:

(1) *Permanent*.—Permanent systems are those having the pipes permanently located. Usually the pipes are buried and do not interfere with farm-work. Installation costs are much higher, but labor and maintenance costs are less than for semipermanent or portable systems. Permanent systems using movable sprinkler heads and quick-coupled riser

pipes are used primarily in nurseries, orchards, citrus groves requiring overtree sprinklers, and for other high-value crops.

(2) *Semipermanent*.—Semipermanent systems usually have the main lines buried and the laterals portable. The water supply is from a fixed point. This type of system is used where the area to be sprinkled is permanently located. Installation costs are somewhat less than for permanent systems but labor and maintenance costs are more.

(3) *Portable*.—Portable systems have both portable main lines and laterals. Installation costs are less than for permanent and semipermanent systems since both mains and laterals can be used in more than one location. Labor and maintenance costs are higher. These systems are designed to be moved around the farm from field to field or even from farm to farm. The portable system with a fixed water supply is especially adapted to the irrigation of crops in a rotation with nonirrigated crops. If water is available at several locations on a farm, the system can be operated with a portable pump. This generally reduces the initial cost and provides for flexible operation in the irrigation of one or more crops in a rotation.

Kinds of Equipment

The component parts of all sprinkler systems are generally similar (fig. 21). Pumps provide the needed pressure. Supply, main, and lateral pipelines convey the water to the sprinklers. Special equipment can and often should be added to improve operations and reduce labor requirements.

Pumps

Sprinkler systems require fairly high-pressure pumps, such as the turbine and horizontal centrifugal types. Turbine pumps are used to pump from deep ground water. Centrifugal pumps are used with surface water supplies and shallow wells. For further information on size and kind of pumps refer to the section on Pumps.

Supply lines

Supply lines convey the water from the pump to the main line on the field to be irrigated. Permanent lines can be used where it is not necessary to move during the irrigation season; otherwise portable lines are more economical. Permanent lines should be buried deep enough not to interfere with farming operations. A way to drain the line to prevent damage from freezing must be provided. Steel, iron, asbestos cement, plastic pipe, and reinforced concrete with special joints are suitable materials for buried lines. Light-weight aluminum lines are best for portable supply lines.

Main lines

Main lines convey the water from the supply line to the lateral lines. Buried permanent mains make farming operations easier and require less maintenance than portable lines. Portable mains are more

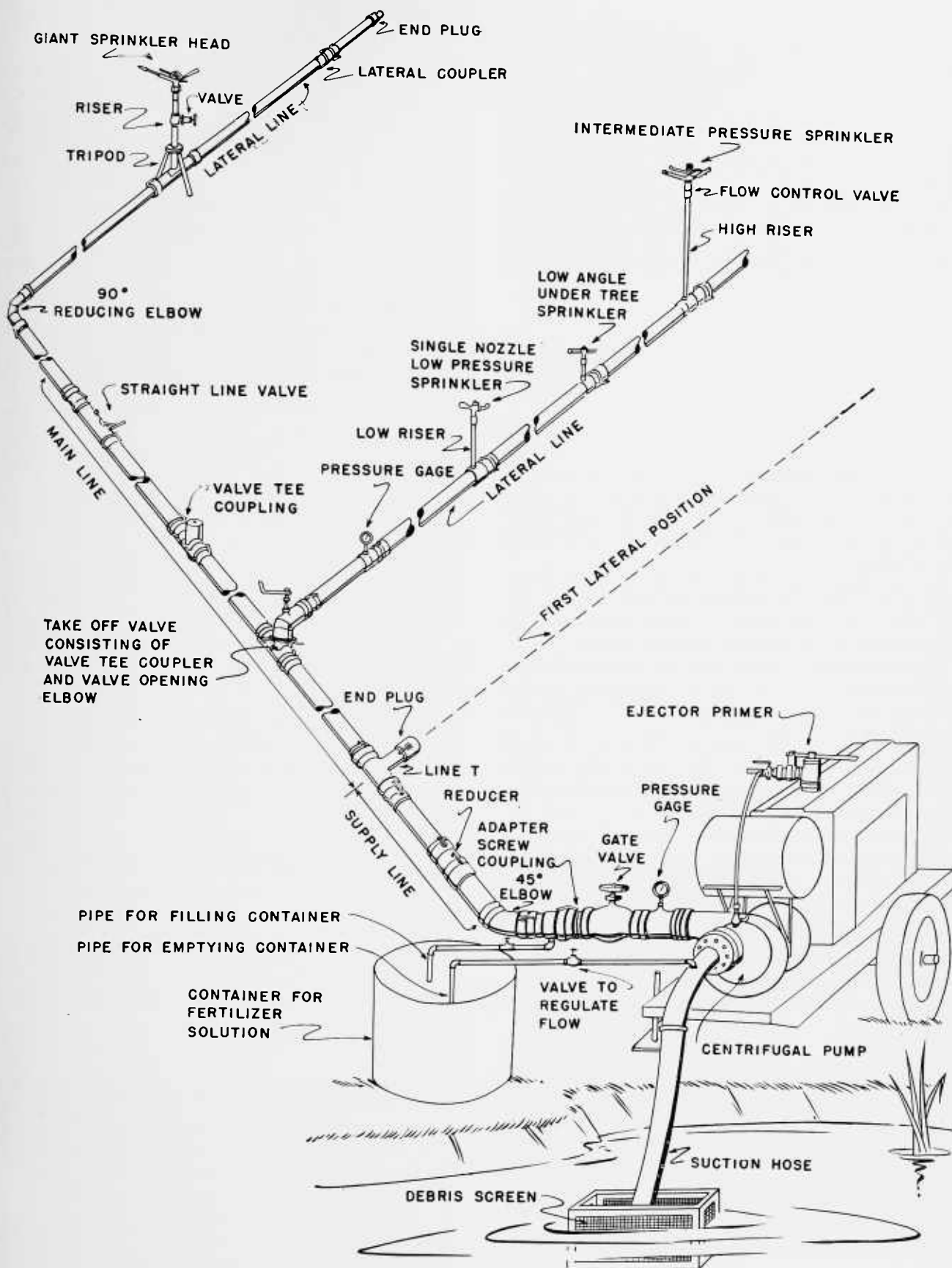
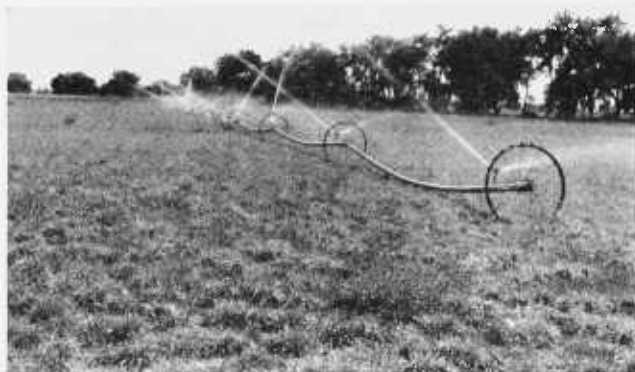


Figure 21.—The parts of a sprinkler irrigation system.



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Figure 22.—A side-roll lateral.

economical, especially when used to irrigate several fields; however, they require more labor. The same materials are suitable for mains as for supply lines.

Laterals

Lateral lines convey the water from the main to the sprinklers. Quick-coupled aluminum pipe is the best for most portable laterals. Buried permanent laterals are sometimes used for orchards, nurseries, and small gardens.

Special types of sprinkler laterals have been developed to save labor in moving the lines. These special types are almost always more costly than the conventional quick-coupled portable lateral.

Side-roll laterals.—Some laterals are moved by a hand-propelled or power-driven mechanism located at about the center of the line (fig. 22). Each line is mounted on wheels with the pipe serving as an axle. It is connected to the main line by a length of flexible hose. This type of lateral is best adapted for use with close-growing crops on rectangular, smooth, well-drained fields.

Pull-type laterals.—Another type of lateral is mounted on wheels or skids and pulled lengthwise with a tractor or truck (fig. 23). Each lateral is towed in a curved route to where the pipe is in line with the new lateral position; it is then pulled back and joined to the main line. Pull-type laterals are usually used with forage crops grown on medium to sandy soils that remain firm when wet. Some crop damage may result when the lines are pulled across muddy fields.

Self-propelled laterals.—A single lateral mounted on wheels that are driven by hydraulic cylinders rotates around the field with one end pivoted at the center. Water is fed into the system at the pivot from a well located there or from a supply piped to that point. The size of sprinkler nozzles increases outward from the pivot so that the amount of water discharged is varied to compensate for the increasing area covered by each sprinkler. This type of system is adapted to square, flat fields. Special provision must be made to irrigate the corners which fall outside the range of the last sprinkler.

Sprinklers

Sprinklers spray the water onto the land through nozzles on the sprinkler heads which may be of either revolving or stationary type. Revolving-head (fig. 24) sprinklers are most widely used for farm crops.

The single-nozzle head usually has a small nozzle and the sprinklers are close-spaced along the lateral line. The two-nozzle head has one nozzle, called a range nozzle, set to throw water to the outer part of the wetted circle. The other, called the spreader nozzle, is smaller and applies water to the area near the sprinkler. Sprinklers of this kind can be used to apply water at average rates of 0.2 to 1.0 inch or more per hour.

Revolving-head sprinklers operate satisfactorily through a wide range of application rates and operating pressures. They are classified as follows:

Low-pressure sprinklers.—Sprinklers that operate at 5 to 15 pounds pressure per square inch are designed with special thrust springs or reaction-type arms to operate at low pressures. They will apply water at relatively high rates over small wetted diameters. Only a fair distribution pattern can be expected. Because of the low operating pressure, the waterdrops are fairly large and may cause puddling of bare soil.

Low-pressure sprinklers are adapted to small acreages where gravity pressure can be utilized. Their use is confined to soils where intake rates are more than 0.5 inch per hour.

Moderate-pressure sprinklers.—Sprinklers that operate at 15 to 30 pounds pressure per square inch are usually designed with a single oscillating nozzle or a long-arm double nozzle. They are capable of a fairly wide range of application rates at recommended spacings over moderate wetted diameters. The distribution pattern is reasonably good at the upper pressure limits. The waterdrops can be broken up fairly well with proper pressure.

Moderate-pressure sprinklers are adapted primarily to undertree sprinkling in orchards. They can be used for small acreages of field crops with pressures of 20 to 30 pounds per square inch.

Intermediate-pressure sprinklers.—Sprinklers that operate at 30 to 60 pounds pressure per square inch are commonly designed with two nozzles that discharge water to an inner and an outer circle. This type of sprinkler has a wide range of application



WN-90012

Figure 23.—A pull-type lateral.

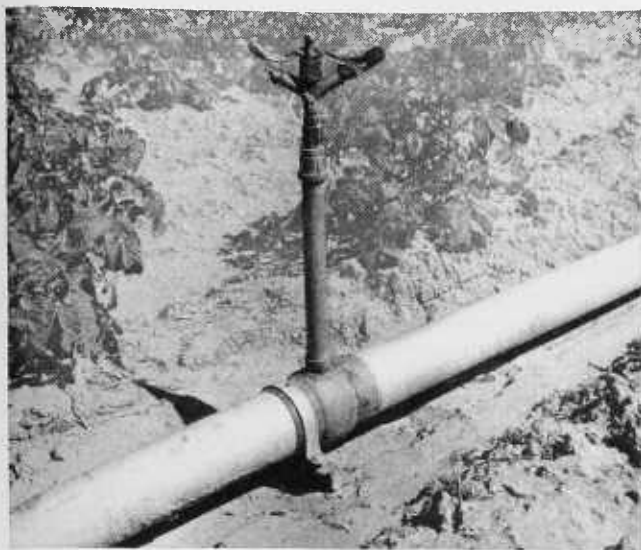


Figure 24.—A revolving-head sprinkler.

rates at recommended spacings. Wetted diameters are 70 to 130 feet. Waterdrops can be well broken up with proper combinations of operating pressure and nozzle size. Under these conditions, distribution patterns are usually very good.

Intermediate-pressure sprinklers are probably the most popular because they are adapted to a wide variety of soils and crops and can be used successfully for overtree systems in orchards.

High-pressure sprinklers.—High-pressure sprinklers are similar to intermediate-pressure sprinklers except that they are designed to operate at pressures of 60 to 100 pounds per square inch. Application rates at recommended spacings exceed 0.3 inch per hour, with rates above 0.5 inch being more common. The wetted diameter ranges from 120 to 230 feet. Distribution patterns are good except when wind velocity is high; then maximum spacings need to be reduced as wind increases.

Sprinklers of this type are primarily adapted to truck crops, field crops, and pasture, particularly on finer-textured soils. They provide fast coverage with limited equipment.

Giant or hydraulic-type sprinklers.—Giant sprinklers are designed to discharge a large high-velocity stream of 100 to 600 g. p. m. into the air at pressures of more than 80 to 120 pounds per square inch. Air resistance breaks up the stream into fine drops. Application rates at recommended spacings usually exceed 0.5 inch per hour. Wetted diameters range from 200 to 400 feet. The distribution pattern is acceptable when the air is calm. Waterdrops are well broken up when design pressures are maintained. Some washing of the soil may occur with clean-tilled crops as the sprinkler is starting or stopping.

Giant sprinklers are adapted to the irrigation of pastures, tall-growing crops, such as corn, where the moving of pipe is difficult, and on isolated areas that require complicated lateral settings when smaller sprinklers are used. They are often used because they can cover large areas rapidly and labor requirements for moving are less than for smaller sprinklers.

Cost of operation is usually higher due to the high operating pressure required. They should be used only on soils that take water rapidly.

Undertree sprinklers.—Some sprinklers are designed to keep the nozzle streams below the tree foliage and fruit in orchards. Stream trajectories are lowered by changing the angle of the nozzles. Wetted diameters are limited by the flat water stream. Where coverage is confined to a single tree interspace, application rates are generally above 0.3 inch per hour. Where laterals can be moved more than one interspace each setting, the range of water application is increased. Moisture-distribution patterns are fairly good. When laterals are moved more than one tree interspace, shifting of the lateral to give a diamond pattern of sprinkler settings helps to offset the effect of interference by the trees with the distribution of the spray. Placing the sprinkler lines in alternate tree rows on succeeding irrigations will even the overall distribution.

Undertree sprinklers are adapted to all orchards but are recommended especially for soft fruits subject to damage by water contact and where wind distorts overtree sprinkler patterns (fig. 25).

Overtree sprinklers.—Regular moderate- to intermediate-pressure sprinklers can be mounted on risers high enough for the stream to clear the trees at least 20 feet from the sprinkler. Moisture distribution is normally good, but heavy foliage tends to concentrate water around the edge of the tree where it drops from the foliage. These sprinklers are adapted to use with all fruits not subject to damage from water contact, such as citrus and apples.

Perforated pipe

A perforated pipe sprinkler system (fig. 26) sprays the water out of small holes in the upper part of the lateral pipe. Usually several rows of perforations are used so that the jets of water cover a rectangular pattern on both sides of the pipe with fair uniformity. Perforated pipe is normally operated at pressures of



CAL-4374

Figure 25.—Undertree sprinklers used in an orchard.



CAL-6957

Figure 26.—Perforated pipe being used to irrigate pasture.

15 to 25 pounds per square inch. This method is primarily adapted to land of gentle and uniform slope. Its use is generally limited to soils having intake rates of 1 inch or more per hour. Wind seriously affects the distribution pattern. Since the pipe lies on the ground, tall crops interfere with the water distribution.

Some perforated pipe systems have only one row of holes and distribute the water by oscillating the pipe through an arc of about 180° with a water-powered motor. The pipe is supported 3 to 8 feet above the ground on posts fitted with roller sockets so it can turn with little friction. These oscillating sprinklers are most commonly used for permanent systems in small nurseries and vegetable gardens.

Special equipment

Special equipment can be added to the sprinkler system to improve performance, reduce labor requirements, and facilitate operations.

Valves are used to control pressure in the lateral lines. They are needed in systems where main-line pressures vary significantly at lateral takeoff points. Takeoff valves can be used where the main and lateral join, or straight-line valves can be located in either the main or lateral line. In multiple-lateral systems, these valves permit moving individual laterals without shutting down the entire system. This saves labor, especially when the lateral is some distance from the pump.

Flow-control valves are used to regulate the pressure and discharge of individual sprinklers where topography causes unequal pressures along the laterals. They are seldom needed on level fields or smooth slopes. Automatic backflow-control valves protect equipment where water is pumped to high elevations.

Pressure gages tell the operator whether the required pressure is being supplied to the system. A gage on the discharge side of the pump checks on pump operation. A gage on the lateral just off the main line helps in regulating pressures in the lateral.

This is needed especially on rolling land where the required lateral-line pressure varies with different settings. A pitot gage is used for checking pressures at the individual nozzles.

Debris screens or strainers are usually needed to keep the system free of trash that might plug the sprinkler nozzles if the water comes from a stream, ditch, lake, or reservoir. Details of design will vary according to the size and amount of debris carried in the water.

Desilting basins may be required to trap sand and suspended silt in water from streams and open ditches. Desilting basins and debris screens can often be combined.

Booster pumps may reduce operating costs when used to provide adequate pressure for small areas that lie considerably above the main irrigated area. This permits the main part of the system to operate at lower pressures than would be required if the entire system were served by one pump.

Design of System

Designing a sprinkler system to fit soils, crops, and labor conditions of an individual farm and to deliver water in the amounts and rates required by the farm irrigation plan is an engineering job. The parts of the system must be fitted together to operate efficiently and economically. Therefore, it is generally best to purchase the entire system from one dealer who will follow adequate design criteria and guarantee the operating efficiency of the system.

The American Society of Agricultural Engineers and the Sprinkler Irrigation Association have developed and published a list of "Minimum Requirements for the Design, Installation and Performance of Sprinkler Irrigation Equipment" (Appendix). These standards should guide the planning of a system to fit the general requirements of the farm irrigation plan.

System layout

The layout of the system must be fitted to the conditions on each farm discussed in the section on Surveys for Planning. For a single field of regular shape, the layout may be simple. When the system is to be used on several fields or on odd-shaped areas, developing the plan may be a full-scale engineering problem requiring alternate layouts and careful analysis of economical pipe sizes.

Some of the most important factors to consider in system layout are the following:

Soils.—The soil survey used in making the general farm irrigation plan is an important guide in deciding specifications of the system.

More detailed examinations are needed to find significant differences in water-intake rates, available moisture-holding capacities, and effective soil depths. When a field has soil areas differing significantly in these respects, it may be wise to subdivide it on the basis of the amount to be applied at each irrigation. If the intake rate varies for the different soils, the system should be designed to apply water so as not to exceed the slowest rate.

Topography.—Topographic conditions must be investigated to determine the general land slope and the maximum differences in elevation. This is needed for (1) locating laterals and main lines, (2) controlling variations in sprinkler discharge due to pressure changes, and (3) computing pump and motor requirements.

Generally, main lines should run up and down the slope and laterals across the slope to minimize variations in pressure at the sprinkler heads. Figure

27 illustrates alternative layouts to fit variations in topography.

Crops.—The types of crops to be grown on the irrigated area must be considered. Orchards and vineyards generally limit sprinkler system layout, sprinkler spacing, and types of sprinkler heads. Different crops, and the use of cover crops and mulch in the rotation, may affect peak water-use requirements and water application rates.

Shape of field.—Irregular-shaped fields generally

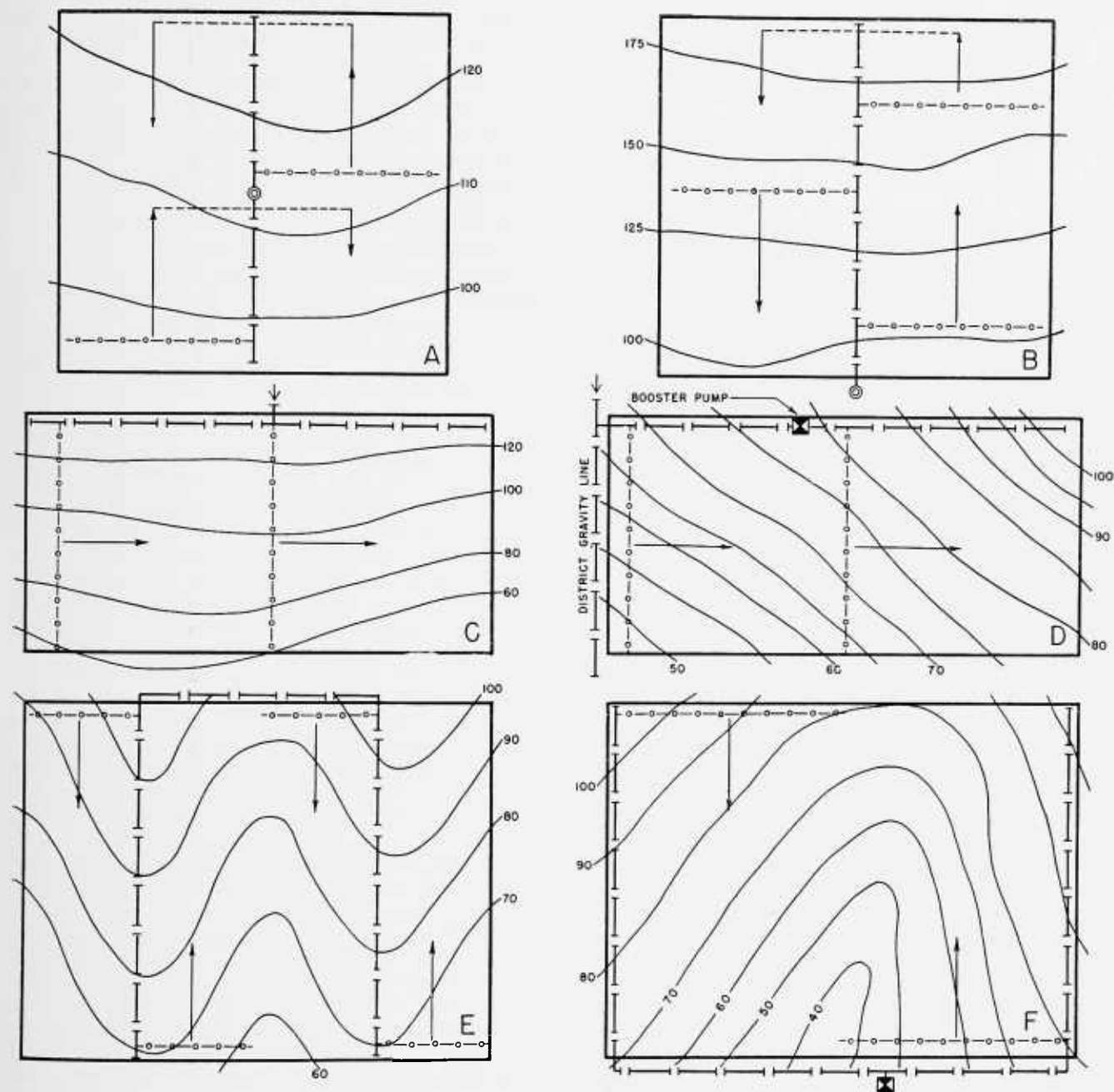


Figure 27.—Some typical layouts of sprinkler systems showing effects of topography: (A) Layout on moderate, uniform slopes with water supply in center; (B) layout illustrating use of odd number of laterals to provide required number of operating sprinklers; (C) layout with gravity pressure where pressure gain approximates friction loss and permits running lateral downhill; (D) layout illustrating area where laterals have to be laid downslope to avoid pressure variation caused by running laterals upslope; (E) layout with two main lines on ridges to avoid running lateral uphill; and (F) layout with two main lines on the sides of the area to avoid running laterals uphill.

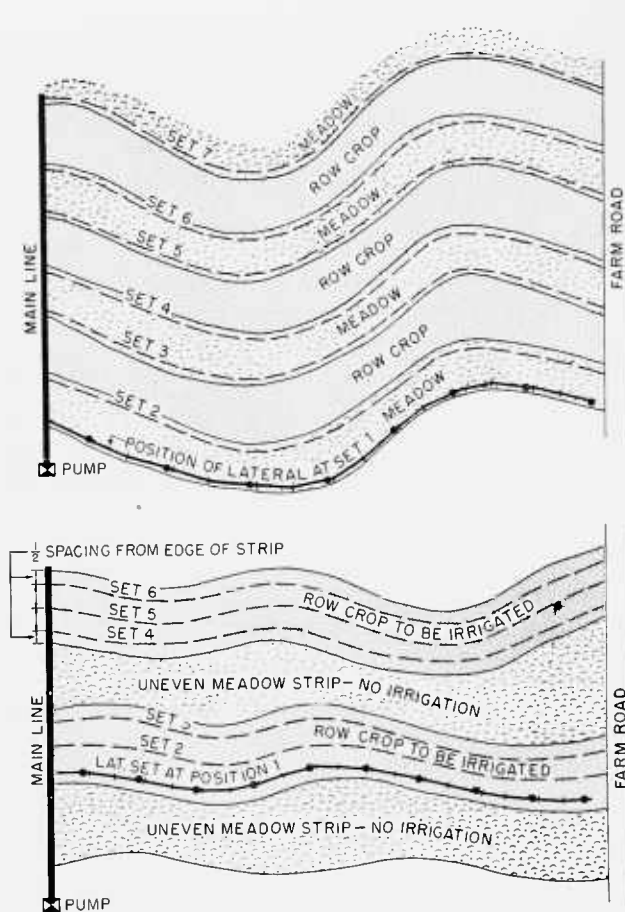


Figure 28.—Examples of system layout with stripcropping: (Top), where both meadow and row crops are to be irrigated at the same time; (bottom), where only the row crops are to be irrigated.

increase the initial cost of the system and make operation more difficult. The system layout should permit the use of as near the same number of sprinklers at each lateral setting as possible. Therefore, fields of uniform width and length best fit the pattern of sprinkler layout. Sometimes the boundaries of irregular-shaped fields can be changed to fit this rectangular pattern. The layout must be such that the number of settings for each lateral required to cover the field does not exceed the number of settings per day times the maximum number of days between irrigations in the peak use period.

Conservation practices.—The sprinkler system layout and the conservation practices on the same field need to be coordinated. On a contour stripcropped field the laterals should follow the strips as nearly as possible, and spacing of laterals and strips need to be adjusted to one another (fig. 28). When both crops of a stripcropping pattern are to be irrigated at the same time, the width of strips should be equal to the lateral spacing. By placing the laterals on the meadow strips, damage to small row crops is avoided, and it is not necessary to walk on muddy ground to move the lines.

If the meadow strip is not to be irrigated with the row crop the width of row-crop strip should be some multiple of the lateral spacing. Even so, some over-

lapping of the sprinkler spray onto the meadow strip will be necessary to insure uniform water distribution over the strip being irrigated. If the row-crop strip is of uniform width the lateral can be laid the full length between two rows. Crossing of rows with the pipe may damage some crops, such as strawberries.

Crop strips need to follow gentle curves so the laterals can bend enough at the connections to follow the rows or strip boundaries. Generally, 20-foot lengths of pipe are best for contour stripcropped fields. Leveling or smoothing the ground before laying out the system may make possible more uniform width of strips and long gentle curves.

Layout and operation will be easier on terraced land if parallel terraces can be used. On fields with nonparallel terraces, laterals may have to cross terraces. Land leveling or smoothing prior to constructing the terraces helps to straighten out their alignment and may make possible the use of parallel terraces.

The system must be designed to properly irrigate the different crops in the rotation.

Water supply.—The location of the water supply affects the design and layout of the system. A water supply near the center of the area to be irrigated permits shorter mains and a cheaper system than if the source is near the edge or outside. Not only more but larger pipes are required for main and supply lines if water must be pumped an extra distance.

Labor supply.—Farm operation schedules and availability of labor are important factors of design. Minimum labor requirements usually call for the greatest initial investment for equipment. If no extra labor is available on the farm for irrigation, the system is usually designed for either one or two sets per 24-hour day; sprinklers are moved in the morning or evening, or both, as a routine farm chore. This type of operation requires more equipment than if the system is designed for more frequent moves and more hours of operation per day. Irrigation schedules and the moving of equipment should be planned for least interference with other farming activities, such as cultivation, spraying, harvesting, or rotation grazing schedules. Extra equipment is sometimes required to fit irrigation into the overall farming operation.

Criteria for system layout.—The following points are a guide to the layout of mains, submains, and laterals:

- (1) Provide for the simultaneous operation of the number of sprinklers which will discharge the required amount of water.
- (2) The number of settings for each operating lateral must not exceed the number of settings per day times the maximum number of days allowed for completing the irrigation during the peak use period.
- (3) Select lateral lengths and pipe sizes so pressure along the laterals will not vary more than 30 percent, and preferably not more than 20 percent.
- (4) Run main lines up and down the predominant land slopes.
- (5) Run laterals across slope as nearly on the

contour as possible to minimize pressure variation.

(6) Use pipe of one, or not more than two, sizes in laterals, especially in systems with more than one lateral.

(7) If there is a choice of water sources, the one nearest the center of the design area will result in the most economical combination of pipe sizes.

(8) Split-line operation with 2, 4, or 6 laterals operating at the same time is desirable for large areas.

(9) Plan the layout to rotate multiple laterals so as to avoid long hauls back to the starting position.

(10) Consider areas of significantly different soils in the same field.

(11) Rough, rolling, or broken topography often calls for major modifications in design.

Sprinkler selection and spacing

Sprinklers must be selected to fit the soil and crop requirements previously discussed. They must not apply water at an average rate faster than the intake rate of the soil. Manufacturers list sprinkler nozzle sizes, pressures, and application rates for different spacings for the sprinklers they produce. The planner of a system can select from this information one of several combinations which meet the limiting intake rate of the soil (Appendix).

The discharge rate of a sprinkler system can be adjusted through a wide range by varying sprinkler type, nozzle size, and operating pressure. In deciding the best spacing, it is, therefore, possible to consider other factors, such as uniformity of application, wind velocity and direction, riser height, crops, farming operations, and labor schedules.

Each sprinkler applies water in a circular area. The diameter of the wetted area is governed by the nozzle size and the water pressure. The water does not fall evenly over the area, but more reaches the ground near the sprinkler than at the outer edge of the circle. Variations in pressure affect both the

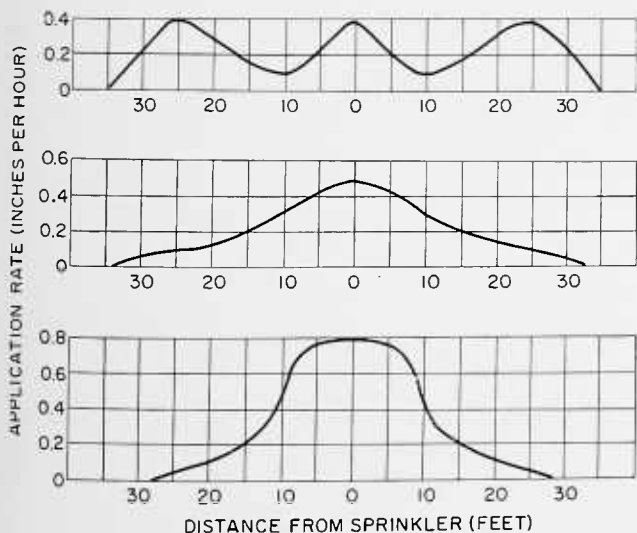


Figure 29.—Patterns of water application by a rotating-type sprinkler operating at different pressures: (Top), pressure too low; (center), pressure satisfactory; (bottom), pressure too high.

rate of discharge and the pattern of distribution (fig. 29).

Therefore, for uniform application, the sprinklers need to be spaced so their wetted areas overlap (fig. 30). The distance between sprinkler heads on

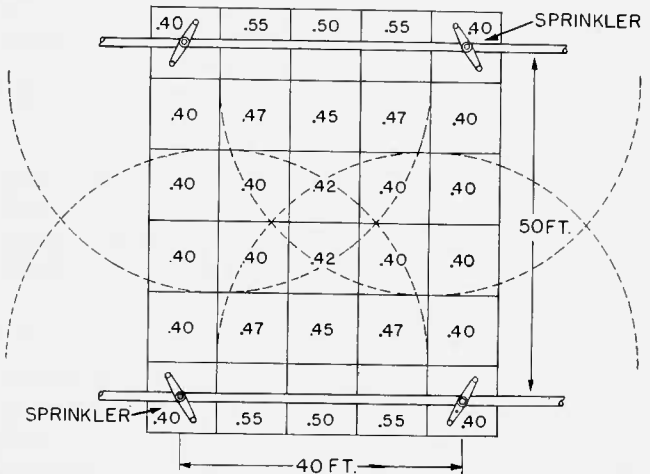


Figure 30.—Combined application of water from four overlapping sprinklers spaced 40 x 50 feet; average application rate 0.43 inch per hour.

the laterals should be 0.3 to 0.5 the diameter of the wetted circle; the distance between lateral positions, or the distance the lateral is moved, should not exceed 0.65 the wetted diameter. This lateral spacing should be reduced to about 0.3 the wetted diameter in areas where wind velocities frequently are more than 10 miles per hour. For each spacing a certain average pressure must be maintained at the sprinkler to discharge water at a particular rate.

Each system is designed for a certain sprinkler size, spacing, and operating pressure; it must be operated as designed if it is to give satisfactory results. Changing the spacing or number of sprinklers, adding or substituting pipe, or operating at a different pressure will throw the system out of balance so that correct application of water is not possible.

Maintenance of Equipment

Though relatively simple, the maintenance of sprinkler equipment is highly important. Lack of care can cause a delay in irrigation at a crucial time that may result in reduced yield or even failure of the crop. All equipment should be inspected periodically; worn or damaged parts should be replaced at once.

Pumps and power units are most likely to suffer from neglect. The manufacturer's recommendations should be followed closely in operating and maintaining these units.

Care in handling and hauling portable pipe, sprinklers, and risers is especially important. Improper handling of this equipment often causes more damage than wear in use.

Most maintenance work can be done in the winter, in rainy seasons, or at other times when the system

is not in use. A few off-season maintenance jobs are:

- (1) Take sprinkler heads apart and inspect them for excessive wear.
- (2) Replace enlarged nozzles. Some suppliers offer this service to their customers and charge only for repair parts.
- (3) Clean portable irrigation pipe and replace worn gaskets.
- (4) Store pipe above the ground, preferably indoors.
- (5) Give special attention to pumps, motors, and internal combustion engines and to such safety devices as low-pressure and high-temperature cutoff switches. A qualified mechanic should inspect these, and repairs and replacements should be made promptly.

Applying Fertilizer in Water

With a sprinkler irrigation system many fertilizers can be applied in the irrigation water to almost any crop at any time during the growing season. This method is quick, economical, easy, and effective, and requires little extra equipment. The uniformity of fertilizer application is the same as that of water distribution.

The major fertilizer materials differ in the way in which they can be applied because of differences in their chemical activity in the soil.

Most nitrogen fertilizers dissolve readily in water and can be applied through sprinklers provided they do not contain free ammonia.

Potash also can be applied through the sprinkler system, but there is little to recommend this method unless unexpected potash deficiencies occur during the growing period.

Phosphorous fertilizers are only partly soluble in water. Therefore, this material usually is best applied dry before or at the time of planting. Ammonium phosphate is water-soluble and can be applied through the irrigation system, but the phosphates are likely to become fixed by combination with calcium in the soil and not move down through the profile like nitrogen and potash.

TABLE 4.—Amount of fertilizer to use for each setting of sprinkler line ¹

Length of line (Feet)	Distance moved each setting	Nutrient applied per acre—			
		20 pounds	40 pounds	60 pounds	100 pounds
	Feet	Pounds	Pounds	Pounds	Pounds
330.....	40	6	12	18	30
	60	9	18	27	45
	80	12	24	36	60
660.....	40	12	24	36	60
	60	18	36	54	90
	80	24	48	72	120
990.....	40	18	36	54	90
	60	27	54	81	135
	80	36	72	108	180

¹ From Mich. Agr. Ext. Bul. 324, Fertilizing Through Irrigation Water.

Other elements, such as boron, magnesium, manganese, and copper, should be applied in dry form. Small amounts can be applied through the irrigation system if deficiencies appear during the growing season.

Amount to apply

The amount of any fertilizer to be run through the system at each setting of the sprinkler line can be figured from table 4. To find the amount of bulk fertilizer required for a certain rate of application, divide the pounds to be applied at each setting by the percentage of the nutrient in the fertilizer. For example, if an application of 40 pounds per acre of nitrogen is recommended, the length of the line is 660 feet, and the distance moved is 60 feet, 36 pounds of nitrogen needs to be applied at each setting. If the fertilizer material is ammonium nitrate containing 33 percent nitrogen, divide 36 by 0.33 to get approximately 110 pounds, the amount of bulk fertilizer needed at each setting.

The approximate percentages of elemental nutrients in fertilizers commonly applied through irrigation water are as follows:

Nitrogen fertilizers:	Percent
Ammonium nitrate.....	33.0
Ammonium sulfate.....	20.5
Sodium nitrate.....	16.0
Cal-nitro.....	20.5
Calcium cyanamide.....	22.0
Potash fertilizers:	
Potassium chloride.....	55.0
Potassium sulfate.....	50.0

Ammonium sulfate is the least soluble of the commonly used solid forms of nitrogen fertilizer. About 280 pounds can be dissolved in 50 gallons of water. About 108 pounds of potassium chloride can be dissolved in 50 gallons of water.

Method of application

The method of adding the fertilizer to the water varies with the type of pump.

Systems using centrifugal pump.—With a centrifugal pump, the fertilizer solution can be drawn into the suction side of the pump (fig. 31). To do this, the suction pipe is tapped near the pump, and a

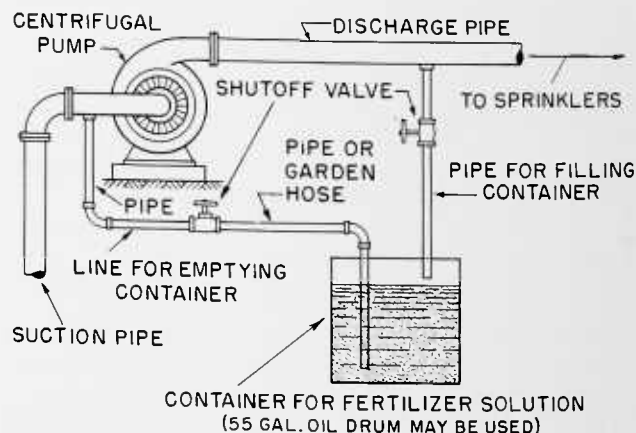


Figure 31.—Equipment for distributing fertilizer through a centrifugal pump.

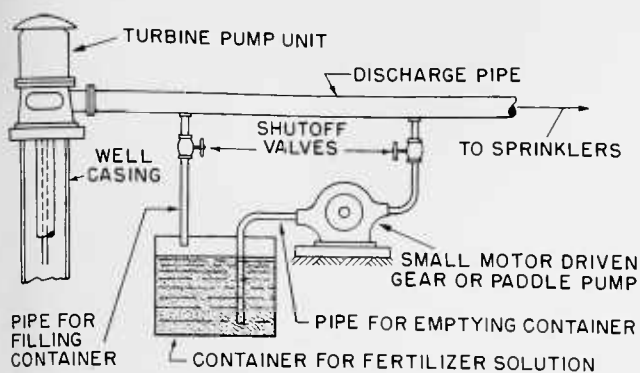


Figure 32.—Equipment for pumping fertilizer solution into discharge pipe of pump or into sprinkler line.

short piece of pipe is threaded into the opening. A valve is attached to the end of this pipe to regulate the flow of the solution. Another piece of pipe or garden hose is attached to the outlet end of the valve with the other end extending to near the bottom of the fertilizer solution container. A similar installation can be made at the discharge side of the pump for filling the container with water to dissolve the fertilizer.

Systems using turbine pumps.—A small pump can be used to inject the solution into the irrigation pump discharge pipe (fig. 32). A rotary, gear, or piston pump, capable of developing pressure higher than that delivered by the irrigation pump, is needed. The small pump of a spray rig is adequate.

Another method is to extend a $\frac{3}{8}$ or $\frac{1}{2}$ -inch copper tube down along the outside of the column of the pump and tap it into the suction pipe below the pump bowls. Some irrigators simply pour the fertilizer or fertilizer solution into the well between the water-delivery column and well casing.

Injecting fertilizer into sprinkler line.—The fertilizer solution can be injected at almost any location on the main line or at the intake of a sprinkler line with a small pump connected as illustrated in figure 32.

Dealers have equipment for introducing fertilizer into the pipeline between the pump and sprinklers.

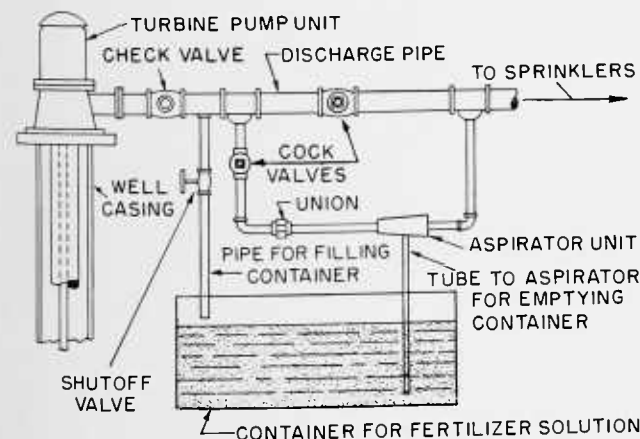


Figure 33.—Equipment using aspirator unit to draw fertilizer solution into pipeline.

These applicators use a pressure difference somewhere in the line, usually between couplers, around elbows, or at a reducer, to force the fertilizer solution into the pipe. A large pressure tank fitted with two valves holds the fertilizer. High-pressure hoses extend from the valves to fittings on the pipe (fig. 33).

Insoluble-type fertilizers must be finely ground to avoid clogging the nozzles. If nozzles are one-eighth inch or larger in diameter they are not likely to stop up.

The fertilizer should be applied toward the end of the setting to avoid loss through leaching. Allow 10 to 20 minutes for applying the fertilizer, then run the system for another 10 to 15 minutes to wash off the plants and clean out the pipelines, pump, and valves.

Frost Control

Sprinkler irrigation systems can be used to protect crops from frost. Since the ordinary sprinkler system covers only a small area with any one setting of the line, it is usually necessary to add lateral lines and sprinklers for adequate frost control. The entire field needs to be covered with a fine mist during the time of freezing temperatures.

The wetted areas of adjoining sprinklers should just meet or overlap slightly. A triangular spacing covers the largest area with the fewest sprinklers.

Application rates of about 0.10 to 0.15 inch per hour are adequate. Very small single-nozzle sprinklers are best. Two-nozzle sprinklers can be used by plugging the spreader nozzle. Satisfactory nozzle size depends upon the spacing, as follows: 60 x 60-foot triangular spacing, $\frac{1}{8}$ - or $\frac{5}{32}$ -inch nozzles; 80 x 80-foot spacing, $\frac{3}{16}$ - or $\frac{7}{32}$ -inch nozzles; and 90 x 90-foot spacing, $\frac{1}{4}$ -inch nozzles. The latter is practical only if the operating pressure is high enough to spray the water over the entire area between sprinklers. Studies at Michigan State University indicated that small single-nozzle sprinklers should complete a circle in 20 seconds or less to control frost.

The frost-control system should be turned on before air temperature at plant level gets down to 32° F. Most growers believe that applying water until the ice is melted off is best. The field becomes a mass of ice, but the temperature stays above freezing point of the plant fluids as long as the water is being applied. Damage usually occurs if the water is turned off too soon after the air temperature rises above 32°. To be safe, the sprinklers should run until all the ice has melted off the plants.

An automatic alarm is needed to warn the irrigator at night when to turn on the system. An electric thermostwitch set at plant level in the field with wires to a loud bell in the house will serve this purpose. The alarm should be set to sound when the temperature reaches 34°. The system should be laid out and tested well in advance of the time when it may be needed.

Frost control with sprinklers has been used successfully on low-growing crops such as tomatoes, cucumbers, peppers, beans, cranberries, and straw-

berries. If the temperature drops far below freezing, the ice that accumulates on trees may be heavy enough to break the branches. Ice is likely to break down such crops as sweet corn, celery, pole beans, and tall flowers. This method of frost control is not practical for tall, thin plants.

Surface Irrigation

Surface irrigation involves transporting and applying water directly on the soil surface. It usually requires some land preparation to shape the surface to control the flow of water. This type of irrigation, therefore, is most applicable to nearly level land where little grading is needed, or to deep soils where considerable earth can be moved without seriously reducing productivity.

An efficient water-distribution system of canals, ditches, or pipelines is essential to successful surface irrigation. It must also provide for control of erosion and for adequate drainage.

The methods of surface irrigation best adapted to humid conditions are (1) furrows, (2) contour borders, and (3) graded borders.

Land Preparation

All surface methods of irrigation require a smooth land surface for uniform distribution of water. Good land preparation to obtain this smoothness is the first step in installing any surface irrigation system.

This job well done gives the following benefits: (1) Efficient control of water resulting in uniform distribution; (2) improved surface drainage, which is especially important in humid areas; (3) less soil erosion and fertility loss because of better control of water; and (4) irrigation of larger acreage with a limited water supply due to more efficient use of water.

Besides land clearing, three types of land preparation are used in humid areas. These, in order of amount of work required, are land smoothing, rough grading, and land leveling. The choice of one over another is governed by the character of the land, the method of irrigation, and the crops involved in each case.

The depth of topsoil that can be disturbed without reducing productivity often limits the extent of leveling that is practical. This is especially true in humid areas where many subsoils are fine textured. Topography also often limits the degree of preparation that is feasible. Where the surface is so irregular that fine leveling would be prohibitive in cost, other crops and methods of irrigation requiring less complete land preparation should be considered.

The method used to apply water often dictates the degree of land preparation required. Some methods require a fine degree of leveling; others require only the removal of minor surface irregularities.

The value of the crop to be irrigated often limits the amount of money that can profitably be spent on land preparation and thereby influences the degree of leveling done.

Land smoothing

Land smoothing, sometimes called "planing," is the removal of minor irregularities in the surface without altering the general topographic pattern. These high and low spots are usually so slight that they are not easily noted by the naked eye. Cuts and fills are correspondingly light.

All irrigable soils can be smoothed, but the practice is useful primarily on nearly level land or land with slight and regular slopes. Land smoothing is also the final operation in land leveling. In one way or another it may be used with any type of irrigation system.

Land smoothing is generally done before laying out a contour border irrigation system. It straightens the contour ridges, makes farming and operation of the system easier, and results in more uniform application of water.

Smoothing can also be used to good advantage with subirrigation. It permits the artificial water table to be controlled at a more nearly uniform depth below the land surface, resulting in more even crop growth over the field.

Where sprinkler irrigation is to be used on nearly level, poorly drained land, smoothing may be the most practical means of providing adequate surface drainage.

Surface irregularities are often caused by tillage implements. These can best be removed by periodic land smoothing.

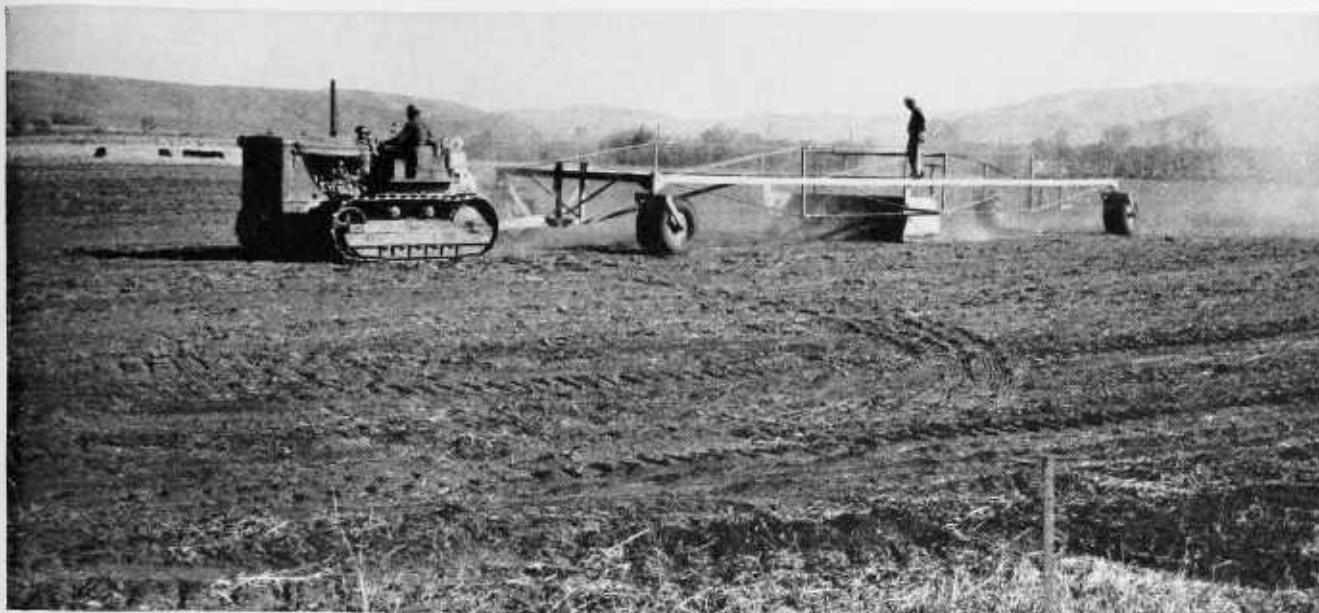
Land smoothing is done with landplanes, levelers, and floats. A landplane has an adjustable blade about the middle of a frame mounted on wheels (fig. 34). Landplanes are made in lengths up to 80 feet and with blade widths up to 15 feet. This great length makes it possible to do a smoother job with this machine than other equipment but large tractors are needed to pull it.

The automatic leveler is smaller than the landplane. It also has a movable blade at about the middle of the frame that automatically loads dirt from the high places and dumps it in the low places. Levelers are available in a variety of sizes, some of which can be pulled by farm tractors (fig. 35). They do a good job of smoothing.

The common wooden float or drag is built in many different designs. Being shorter than the other types of smoothing equipment, these do not leave the land surface nearly so smooth.

All types of smoothing equipment operate on the same principle; i. e., the blade removes the high spots and pushes the soil into low areas ahead. Usually three or more passes of the equipment in cross directions are needed, the last pass being made in the direction of irrigation.

Land smoothing is usually contracted for either by the acre or by the hour. The cost depends on the type of equipment used and the number of "passes" made over the land. Costs usually range from \$1.50 to \$2.00 per acre for each pass of the landplane.



NEV-696

Figure 34.—Smoothing land with a 60-foot landplane.

Rough grading

Rough grading is the removal of knolls, mounds, or ridges, and the filling of pockets, gullies, and other low areas in a field. These irregularities are much greater than those described under land smoothing and are clearly visible. Cuts are relatively heavy, often amounting to 2 feet or more. Rough grading is usually followed by land smoothing or land leveling.

Since knolls or mounds normally occupy only a small percentage of a field suitable for irrigation, the productive topsoil is not disturbed over a wide area. Therefore, this type of land preparation can be used on most irrigable soils and under all topographic conditions where surface irrigation is adapted.

It is good practice to excavate the high spots to about 6 inches below the finished ground surface and to fill the holes with topsoil from adjacent areas. Allowance needs to be made for settling of the fills and swelling of cuts.

If the soil removed from the high spots can be placed in nearby low areas or spread over adjacent areas—which it usually can—a track-type tractor and dozer blade can be used most economically (fig. 36). For long hauls, a rubber-tired carrier-type scraper pulled by a large tractor is more economical.

Rough grading is usually contracted for by the equipment-operating hour, since the yardage of excavation is difficult to estimate without unwarranted time-consuming field surveys.



Figure 35.—Automatic leveler pulled by farm tractor.



LA-61750

Figure 36.—Rough grading with a bulldozer.



AZ-5330

Figure 37.—Land leveling with a wheel-type tractor and a carryall scraper.

Land leveling

Land leveling is the reshaping of the land surface to a planned grade. As practiced in humid areas, this usually consists of leveling the surface of each field to one or a series of planes (fig. 37). These planes usually have some slope both in the direction of irrigation and at right angles to this direction.

Land leveling normally is essential to successful and efficient irrigation by either the graded border or graded furrow method. The plane or planes must have slopes suitable to the method of irrigation, as follows:

Graded borders—0.10 to 2.00 feet per 100 feet length of border; 0.00 to 0.10 foot cross slope per border width.

Graded furrows—0.05 to 0.50 foot per 100 feet length of furrow; 0.00 to 2.00 feet per 100 feet cross slope. Cross slope must be reduced where furrows are less than 6 inches deep.

Land leveling is limited to soils that are suitable for irrigation by border or furrow methods and that are deep enough that the needed cuts and fills can be made without permanently reducing productivity. Yields may be lower immediately after some land-leveling jobs, but most soils can be restored to their original productivity in 2 or 3 years by the use of good conservation and soil-management practices. Where damage is likely to be more permanent, land leveling is not practical.

Topography often limits the extent of land leveling that is feasible. In humid areas it is generally considered too costly to move more than 600 cubic yards of earth per acre. Leveling is usually limited to land which can be graded economically to slopes not exceeding 2 feet per 100 feet. Slopes of less than 1 foot per 100 feet are preferable.

A topographic survey is needed to make the land-leveling plan. Such a survey is usually made by

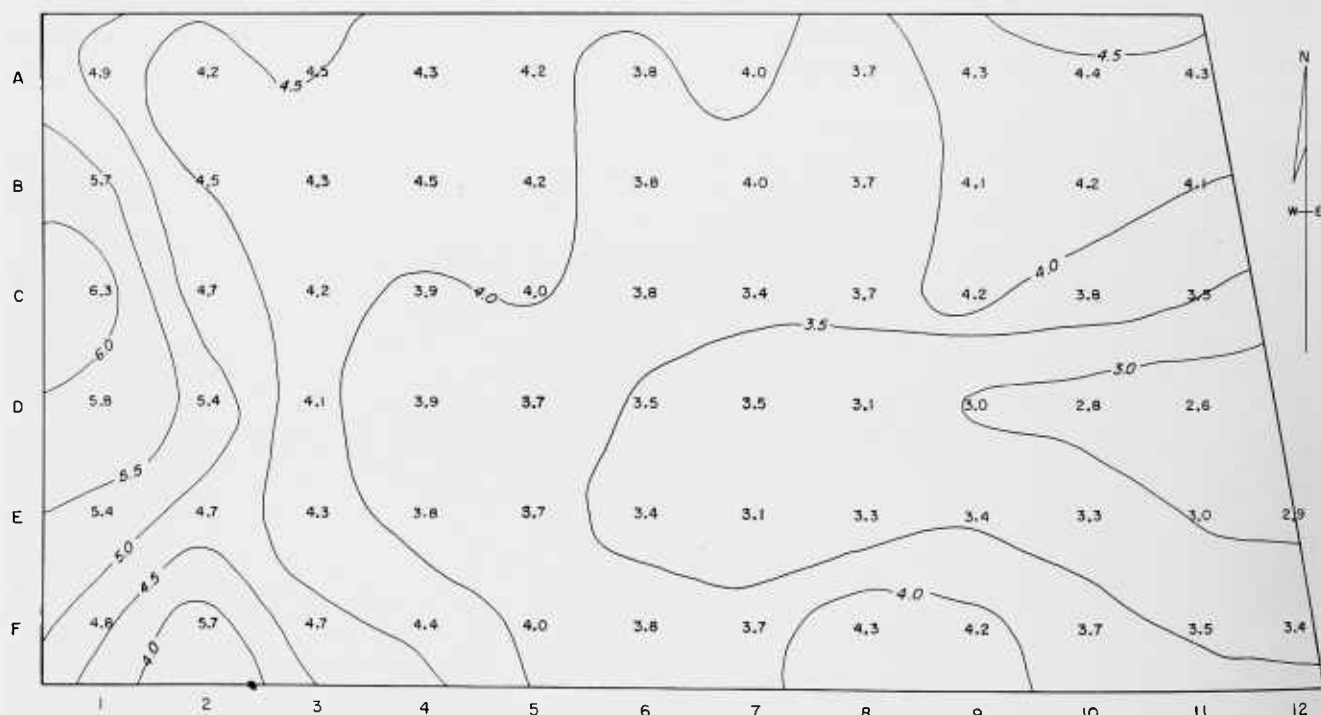


Figure 38.—Topographic map made by grid method, showing elevations at 100-foot spacings and contour lines at 0.5-foot intervals.

the grid method, in which stakes are set and elevations recorded at intervals of 100 feet or less (fig. 38). The stakes are later marked and used as grade stakes in earth moving.

The finished plan can take the form of a land-grading map showing the depth of cut or fill at each stake in a 100-foot grid pattern (fig. 39). Such a map shows the equipment operator at a glance where the material is to be excavated and where it is to be spread.

Making a land-leveling plan is a complex job requiring the services of an experienced engineer. The slopes of the resulting plane must fall within the limits practical for the type of irrigation and still conform as nearly as possible to average slopes before grading if costs are to be held to a minimum. The "cut" yardage must be in near balance with the "fill" yardage with due allowances for compaction and shrinkage.

Differences in slope patterns within a field often require that it be divided into parcels to be leveled separately (fig. 40) if the amount of earth moved is to be kept to a minimum.

If the natural slope is so steep as to require material reduction, the least amount of grading will be needed if each parcel is held to the minimum length that can be irrigated satisfactorily (parcels A and B in fig. 40). Abrupt changes in steepness (parcels B and C and parcels F and G) usually require that each portion be leveled separately. Sharp changes in the direction of maximum slope (parcels D and E), causing borders or furrows to run in different directions, require separate treatment of the parcels.

Where the natural slope is too steep to permit leveling to a plane, or where the soil profile is too shallow to permit deep cuts, the land can be leveled in narrow strips across the main slope. These strips are called "benches" and the practice "bench leveling." Since this method leaves a sharp break in slope between the benches, a ridge is needed along the lower edge of each bench to hold the water and prevent erosion (fig. 41).

The rubber-tired, carrier-type scraper is used on most land-leveling jobs. This implement, with one operator, excavates, loads, hauls, and spreads the earth. These scrapers are pulled by large tractors. Capacities range from 5 to 23 cubic yards. They are especially well adapted to jobs where cuts are heavy or hauls long.

A smaller implement, recently developed, is the elevating scraper. It is also a rubber-tired, carrier scraper that performs all operations with one operator. It is available in 5-, 8-, and 10-cubic-yard sizes and can be pulled by a medium to large farm tractor. It is fast and well suited to most land-leveling jobs.

The rotary scraper is used to a lesser extent in land leveling. It is much smaller and lighter than the carrier scrapers and can be powered by a farm-size tractor. It is especially suitable for light work and is used primarily by farmers who wish to do their own leveling rather than employ a contractor.

After the grading job has been completed and checked by the engineer, there still will be small irregularities in the surface that must be removed. This is best done with a landplane or automatic leveler, as described under Land Smoothing.

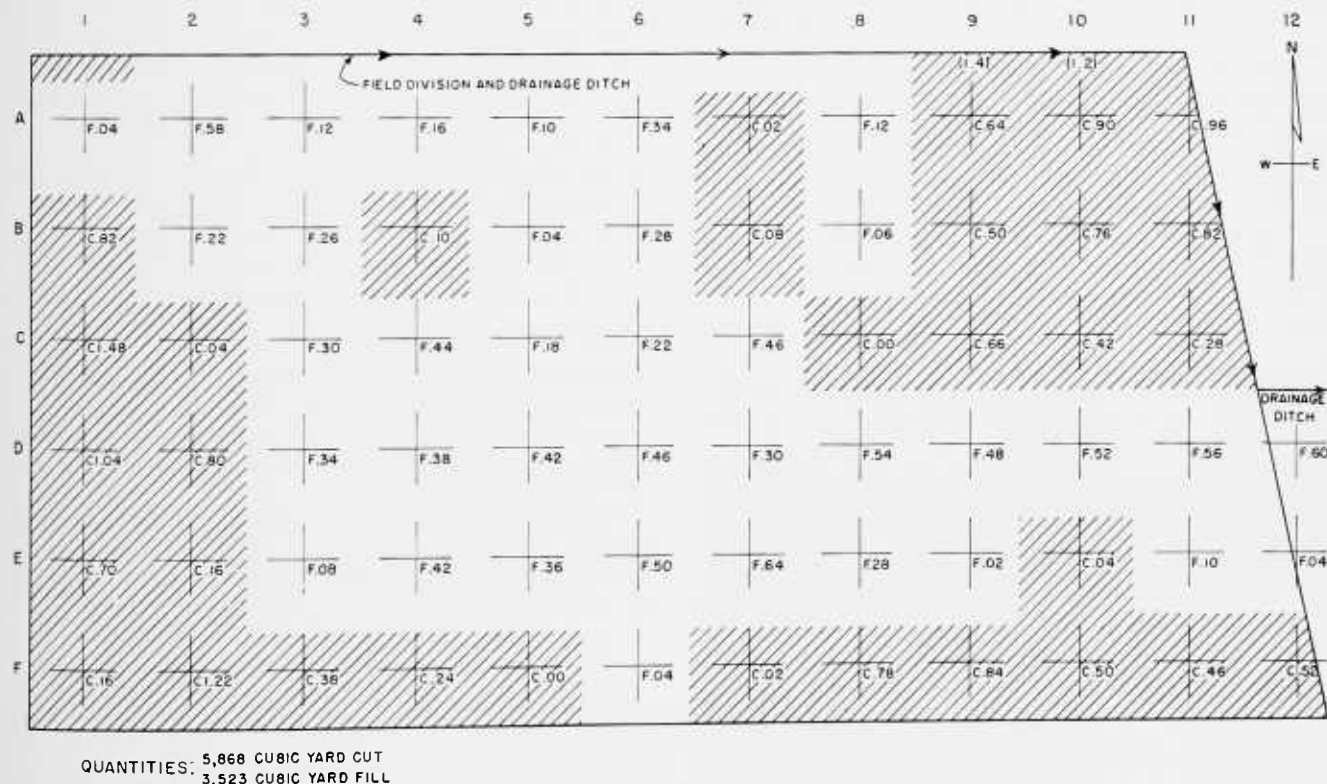


Figure 39.—Leveling-plan map based on topographic map shown in figure 38. Amount of cut or fill is shown on each grade stake left at points where elevations were taken in survey. The shaded area is to be cut, the unshaded is to be filled.

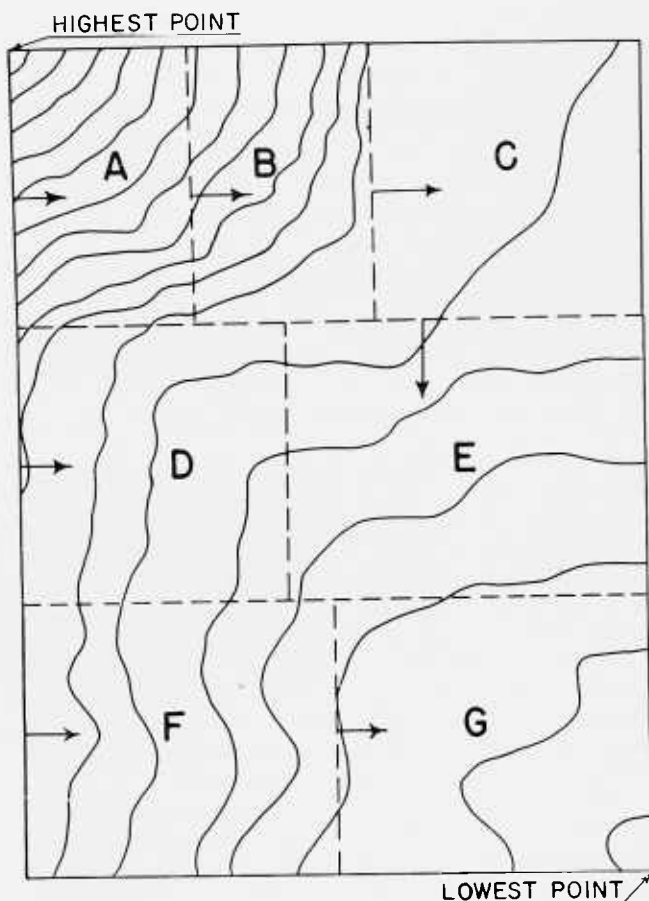


Figure 40.—Division of a field for land leveling to fit slope patterns. Arrows indicate direction of irrigation.

The cost per acre of leveling a field depends on a number of factors; the principal ones are the volume of excavation required and the length of haul. This volume ordinarily varies between 200 and 600 cubic yards per acre. The cost of excavation usually is 12 to 18 cents per cubic yard of earth moved.

A newly leveled field should not be planted immediately to a perennial crop, such as alfalfa. When irrigated, new fills may settle, and the soil in cuts may swell, causing irregularities in the surface.



NEB-1809

Figure 41.—Bench leveling with a motor grader.

For the first year or two after leveling, a field should be planted to annual crops so these irregularities can be removed by smoothing.

Maintenance is required to keep the surface of a leveled field smooth. This can be done by going over a field at least once with a landplane, leveler, or float each time a seedbed is prepared. Plowing must be done to avoid dead furrows and backfurrows. Two-way plows are widely used for this purpose.

Water-Distribution Systems

Ditches or pipelines transport irrigation water from the source of supply to the area to be irrigated. They need to be carefully planned to deliver the required amount of water without excessive losses and without soil erosion.

Ditches

Earth ditches are usually the cheapest way to transport irrigation water on the farm. In some cases, they may serve for both irrigation and drainage.

Ditches are best adapted to clay or loam soils. Excessive seepage does not occur in these soils and ditchbanks are more stable than in sands or sandy loams.

For efficient irrigation, the water surface in the ditch must be 0.5 to 1.0 foot higher than the adjacent ground to be irrigated (fig. 42). To build the ditchbanks to this height usually requires more dirt than should be excavated from the ditch channel. Where land leveling is done, this additional fill material can be supplied as part of the leveling job.

It is important that ditches be large enough to carry the amount of water needed. Ditches that are too small increase labor requirements and result in low irrigation efficiencies. Table 5 gives the ditch sizes needed for different irrigation streams.

When it is planned to irrigate directly out of a ditch with turnouts or siphon tubes, the ditch should be nearly level (less than 0.10 foot fall per 100 feet). In a level ditch, water can be backed up for a maximum distance, requiring a minimum of check dams and labor to control the irrigation flow.

Water-control structures

Ditches should be of gentle grade to avoid high-velocity flows which would cause soil erosion. If irrigation ditches must be constructed on steep slopes, drop structures are necessary to control the velocity of the water (fig. 43).

Other water-control structures, such as checks and chutes, may be needed to control irrigation water and save labor. Checks can be built of concrete

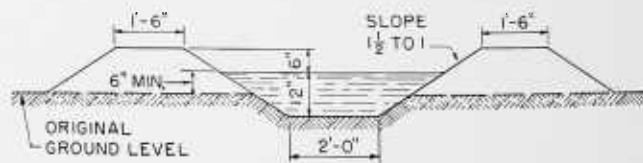


Figure 42.—Cross section of a typical unlined irrigation ditch.

(fig. 44) in the ditch, or can be built of wood or metal and placed in the ditch. By placing stoplogs or flashboards in the structures, the flow of water can be partially or wholly directed into another ditch, thereby controlling the water-surface elevation so the proper irrigation stream is delivered to the furrows or border strips.

Drawings of several types of drops and checks are in the Appendix.

In temporary ditches (those that have to be rebuilt each year), water is usually controlled with portable devices such as canvas, plastic, or metal checks and dams (fig. 45). These structures can be moved for use in different places and can be stored out of the way during the nonirrigation season.

Ditch linings

Earth ditches can be lined with impervious material to prevent excessive seepage and the growth of weeds in the channel.

One of the main problems in the use of earth ditches is the control of weeds. Weeds in a ditch obstruct the flow of water. If allowed to go to seed,

TABLE 5.—*Sizes of ditches required for different irrigation streams.*

GRADE 0.05 FOOT PER 100 FEET

Stream size (Cubic feet per second)	Stream Gallons per minute	Size of ditch ¹	
		Base width	Water depth
		Inches	Inches
0.5.....	225	12	8
1.0.....	450	18	9
2.0.....	900	24	11
4.0.....	1,800	36	13
8.0.....	3,600	48	17

GRADE 0.1 FOOT PER 100 FEET

0.5.....	225	12	6
1.0.....	450	15	9
2.0.....	900	18	10
4.0.....	1,800	24	13
8.0.....	3,600	36	16

GRADE 0.2 FOOT PER 100 FEET

0.5.....	225	12	5
1.0.....	450	15	5
2.0.....	900	18	9
4.0.....	1,800	18	12
8.0.....	3,600	24	15

GRADE 0.5 FOOT PER 100 FEET

0.5.....	225	12	4
1.0.....	450	12	6
2.0.....	900	18	7
4.0.....	1,800	18	10
8.0.....	3,600	24	13

¹ Side slopes 1.5 to 1.



NEB-1808

Figure 43.—A series of concrete chute drops in an irrigation ditch down a steep slope.

they may be spread over the farm in the irrigation water.

Concrete.—Concrete is the most widely used ditch-lining material (fig. 46). It is permanent and fairly cheap, and is readily available in most localities. It will prevent weed growth in channels.

Three methods of lining ditches with concrete are generally used: (1) Hand placement with or without forms, (2) mechanical placement with slip-form, and (3) application under air pressure. All three methods are satisfactory if the following precautions are observed: (1) Proper preparation of subgrade; (2) use of proper kind and proportion of cement, gravel, sand, and water; (3) proper mixing, placing, finishing, and curing of the concrete; and (4) proper maintenance after ditch construction.

Soil cement offers possibilities for use as a ditch-lining material where sand and gravel are not available but where subgrade soils or those nearby are sandy. Soil cement is made of portland cement



NEB-1807

Figure 44.—A concrete check with flashboards in place.



WYO-700

Figure 45.—A canvas check used to turn water in a ditch.

and natural soil. Careful control of the mixture is necessary. The amount of cement to be used depends on the type of material with which it is mixed: normally about 12 percent cement by volume will give satisfactory results.

Asphalt.—Asphaltic concrete and buried asphalt membranes reduce seepage and weed growth, but they are not widely used for farm irrigation ditches because special equipment not readily available to the farmer is required for their installation.

Prefabricated asphalt membranes are manufactured in rolls similar to tarpaper and can be laid easily by hand. This material is subject to damage by livestock and weather. Covering it with a layer of earth prolongs its life but increases the growth of weeds and the difficulty of cleaning ditches.

Butyl fabrics.—Butyl-coated fabrics of fiberglas, cotton, rayon, and nylon have been tested as ditch-lining materials. Butyl reinforced with nylon has given best results. This material is highly resistant to weathering, but is damaged by the trampling of livestock.

Plastics.—Plastic films have shown promise where not subject to damage by livestock.

Earth and bentonite.—Seepage can sometimes be reduced by lining the ditch with one or more layers of impervious silt or clay or with bentonite. In the humid areas, however, this procedure is only a temporary expedient since it does not help in the control of weeds, and earth linings are easily damaged in ditch maintenance.



NEB-1806

Figure 46.—An irrigation ditch lined with concrete.

Pipelines

Pipelines offer many advantages over open ditches for transporting irrigation water. They can be buried so they do not interfere with farming operations, and they require little maintenance. Their primary disadvantage is the high initial cost. Reductions in water losses and labor requirements, however, usually more than offset this additional cost.

Low-pressure pipelines (heads less than 25 feet or pressures less than 10 pounds per square inch) are used primarily with surface irrigation methods. Where the lines are permanent (usually buried), they are often made of concrete or plastics. Portable low-pressure pipelines are usually made of light-weight metal, treated canvas, flexible plastic, or rubber.

High-pressure pipelines are used when operating pressures in excess of about 10 pounds per square inch are required, as with sprinkler systems.

Permanent high-pressure lines are usually buried and are made of steel, asbestos-concrete, or reinforced concrete with special joints. Portable high-pressure lines are usually made of light-weight metal with pressure-seal couplings.

The use of pipelines to carry irrigation water is increasing rapidly in the older irrigated areas. In the humid areas where ditch maintenance costs are high, the use of pipelines is recommended wherever possible.

Applying fertilizer in water

Fertilizer can be applied through a surface irrigation system by placing it in the ditch or pipeline before the water is turned into the furrows or border strips. The fertilizer must first be dissolved and then thoroughly and uniformly mixed with the water.

The dissolved fertilizer can be sprayed into the irrigation stream through nozzles spaced at intervals across the supply ditch a short distance from the area to be fertilized.

Another method is to place a wooden structure consisting of a V-shaped divider and baffles in the supply ditch. A container, such as an oil drum in which the fertilizer has been dissolved, is mounted on the structure so the solution can be discharged into the water at the divider. The turbulence of the water in the structure mixes the fertilizer.

Furrow Irrigation

In furrow irrigation, water is applied by running small streams in furrows between the crop rows. The water soaks into the soil and spreads out into the crop root zone between furrows.

Where adapted

Furrow irrigation can be used with all field crops planted in rows, truck crops, tree fruits, small fruits, and vineyards. The land to be irrigated should have productive soil deep enough to permit needed land leveling without exposing harmful amounts of subsoil. The water-intake rate should be at least 0.2 inch per hour and not more than 4 inches per hour.

Loams and clay loams are best adapted for furrow irrigation because their available moisture-holding capacities are high and their intake rates are right. Very sandy soils are not well adapted because their high intake rates make short rows necessary.

Topography should be smooth and uniform. Irregular topography increases leveling costs and labor requirements.

The land must be leveled so that water can travel the entire length of the row without ponding. This means that all high and low spots must be removed and the land given enough slope to let the water flow down the furrows. The leveled grade must be maintained from year to year.

Water should be available at the rate of at least 10 g. p. m. for each acre to be irrigated.

Some advantages of the furrow method are:

(1) Where land leveling is not excessive, initial investment is low since the furrows made in cultivating row crops can be used to convey water.

(2) Uniform water distribution and high efficiency can be obtained with proper design and operation.

(3) The water does not wet foliage and wash off insecticides.

(4) The required land leveling provides for excellent surface drainage.

(5) Small streams of water can be used efficiently.

Design of system

After land preparation is completed, the system can be designed to fit the soil and topographic features of the field. Furrow spacing, furrow grade, cross slope, furrow streams, and length of run should conform to the local Conservation Irrigation Guide. The specifications in this section will serve as general guides if more specific local information is not available.

Furrow spacing.—Furrows can be spaced to fit the crops grown and the standard machines used for planting and cultivating. Crops like corn and potatoes have furrows between all rows. Bedded crops, such as lettuce, carrots, and onions, may have pairs of rows between furrows. Wide-spaced crops, like tomatoes, fruits, and berries generally require more than one furrow between crop rows.

Furrows are spaced close enough that water will spread from their sides into the ridge and root zone of the crop before too much moves down below the root zone. The way water moves through different soils affects practical spacings of furrows (fig. 47).

Care must be taken during tillage to keep furrows deep enough to carry the irrigation stream. A furrow 6 inches deep is required to carry a furrow stream of 40 to 50 g. p. m.

Furrow grade.—In humid areas, furrow grades should not exceed 0.3 foot per 100 feet. Steeper grades may permit erosion from high intensity storms. Furrow grades up to 0.5 foot per 100 feet may be safe if runs are short enough to prevent accumulation of enough water to cause erosion.

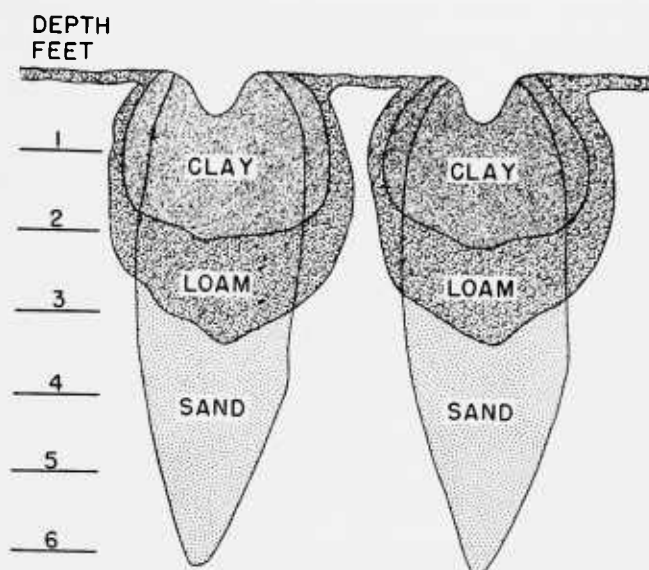


Figure 47.—Typical patterns of moisture penetration by the same amount of water from furrows in different soils.

A minimum furrow grade of 0.05 foot per 100 feet is needed to assure surface drainage.

Cross slope.—The slope of the land at right angles to the direction of irrigation, often called the cross slope, should not exceed 2.0 feet per 100 feet. Where furrows are less than 6 inches deep, the cross slope should be less than 2 percent, and it may be necessary to use shorter runs to prevent accumulation of water and overtopping of the furrows.

Furrow streams.—At the beginning of an irrigation the largest stream of water that will not cause erosion is used in each furrow. This stream, which is allowed to flow until the water reaches the ends of the furrows, is called the "initial" stream. Its purpose is to wet the entire length of each furrow as quickly as possible. Reducing the difference in time that water infiltrates at the upper and lower ends of the furrow gives more uniform distribution of water and improves the efficiency of irrigation.

The size of the initial furrow stream is determined, for the most part, by the furrow grade and cross section. Following are usual maximum nonerosive furrow streams for different furrow grades:

Furrow grade, percent	Gallons per minute
0.05.....	66
.10.....	66
.15.....	66
.20.....	50
.25.....	40
.30.....	33
.40.....	25
.50.....	20

After the initial stream has reached the lower end of a furrow, the stream is reduced or "cut back" to one that will just keep the furrow wet throughout its length with a minimum of waste at the end. This cutback stream flows until the required amount of water has been applied.

TABLE 6.—Intake rate for total area irrigated by furrows

Furrow intake rate (gallons per minute per 100 feet)	Furrow spacing							
	18 inches	20 inches	22 inches	24 inches	27 inches	30 inches	36 inches	48 inches
	<i>Inches per hour</i>	<i>Inches per hour</i>	<i>Inches per hour</i>	<i>Inches per hour</i>	<i>Inches per hour</i>	<i>Inches per hour</i>	<i>Inches per hour</i>	<i>Inches per hour</i>
0.1.....	0.06	0.06	0.05	0.05	0.04	0.04	0.03	0.02
.2.....	.13	.12	.11	.10	.09	.08	.06	.05
.3.....	.19	.17	.16	.14	.13	.12	.10	.07
.4.....	.26	.23	.21	.19	.17	.15	.13	.10
.5.....	.32	.29	.26	.24	.21	.19	.16	.12
.6.....	.39	.35	.32	.29	.26	.23	.19	.14
.7.....	.45	.41	.37	.34	.30	.27	.23	.17
.8.....	.52	.47	.42	.39	.34	.31	.26	.19
.9.....	.58	.52	.48	.44	.39	.35	.29	.22
1.....	.65	.58	.53	.48	.43	.39	.32	.24
2.....	1.29	1.16	1.06	.97	.86	.78	.65	.48
3.....	1.94	1.74	1.58	1.45	1.29	1.16	.97	.73
4.....	2.58	2.33	2.12	1.94	1.72	1.55	1.29	.97
5.....	3.23	2.91	2.64	2.42	2.15	1.94	1.62	1.21
6.....	3.88	3.49	3.17	2.91	2.59	2.33	1.94	1.45
7.....	4.52	4.07	3.70	3.39	3.01	2.72	2.26	1.70
8.....	5.17	4.66	4.23	3.88	3.45	3.10	2.58	1.94
9.....	5.82	5.24	4.76	4.37	3.88	3.49	2.91	2.18
10.....	6.47	5.82	5.29	4.85	4.31	3.88	3.24	2.43

To compute the proper size of cutback streams, the average intake rate of the soil must be known in gallons per minute per 100 feet of furrow. Actual rates should be determined for each field by methods set forth in Agriculture Handbook No. 82, Methods for Evaluating Irrigation Systems, or taken from the local Conservation Irrigation Guide. The usual ranges of intake rates for different textured soils follow:

	<i>Gallons per minute per 100 feet of furrow</i>
Fine textures:	
Dense clays.....	0 to 1
Silty clays to clays.....	0.5 to 2
Clay loams to silt loams.....	1 to 2
Medium textures:	
Silt loams to loams.....	1 to 3
Moderately coarse textures:	
Fine sandy loams to sandy loams.....	1.5 to 10
Coarse textures:	
Loamy fine sands to loamy sands.....	5 to 15

The proper size of the cutback stream is this intake rate times the length of run in hundreds of feet. For example, 800-foot furrows on a silt loam with an intake rate of 2 g. p. m. per 100 feet would take a cutback stream of 16 g. p. m.

To determine how long to allow this stream to run, the amount of water to be applied in inches is divided by the intake rate in inches per hour. This intake rate is affected by the spacing of the furrows, and the furrow-intake rate must be converted to total intake for the irrigated area (table 6). In the example, if the planned application were 4 inches and the spacing of the furrows 36 inches, the cutback stream would need to run $\frac{4}{0.65}$ or 6.1 hours.

It may not be necessary to cut back the initial furrow streams to get high irrigation efficiencies on some soils. This would be true where intake rate is high when water is first applied and very low later. An example is a fine-textured soil that tends to crack upon drying.

If at least three-fourths of the water to be applied is absorbed during the first fourth of the computed irrigation time, the use of cutback streams is questionable. As this ratio increases, the practice has even less value. In such cases a stream in excess of the average intake rate of the soil but less than the maximum allowable nonerosive stream is satisfactory. After this stream wets the lower end of the furrow, the irrigator cuts off the water and turns it into other furrows. Such a procedure results in a saving of labor with little or no sacrifice of efficiency.

Length of run.—The optimum length of run is usually the longest furrow that can be safely and efficiently irrigated. If the run is too long, water soaks in too deep at the head of the furrow by the time the stream reaches the lower end. This means that the upper end of the furrow is overirrigated and the lower end may even be underirrigated. If the run is too short, extra cross ditches are required, and labor requirements will increase.

The length of run best for a particular field is affected by the erosion and drainage hazards, the kinds of soil, the slope of furrow, and the size of stream that the furrow will carry.

The intake rate of the soil affects the length of row that can be irrigated efficiently. Runs must be shorter on a porous sandy soil, for example, than on a tight clay soil on the same slope. Also, the same furrows should not cross two widely different kinds of soil, as from a sandy loam to a clay loam. Rather, the field should be divided so each type of soil can be irrigated separately.

If the furrows are too long on soils having poor internal drainage, runoff from rainfall may collect at the lower ends and damage the crop. The danger of erosion from rainfall may also limit the safe length of run. The size of the furrow also affects the length of run by limiting the size of furrow stream that can be used.

The length of furrow which can be effectively irrigated may be as short as 150 feet on soils with intake rates in excess of 2 inches per hour, or as much as 1,000 feet on soils with low intake rates and free drainage. A good guide is to make runs

of a length that the maximum nonerosive stream reaches the end of the furrow and needs to be cut back in about one-fourth application time. The safe length varies for different furrow grades and amounts of water applied on different soils (table 7).

TABLE 7.—Safe lengths of run for different furrow grades and amounts of water applied on different soils ¹

Furrow grade (percent)	Fine-textured soils		Medium-textured soils		Moderately coarse-textured soils		Coarse-textured soils	
	2-inch irrigation	4-inch irrigation	2-inch irrigation	4-inch irrigation	2-inch irrigation	4-inch irrigation	2-inch irrigation	4-inch irrigation
	<i>Feet</i>	<i>Feet</i>	<i>Feet</i>	<i>Feet</i>	<i>Feet</i>	<i>Feet</i>	<i>Feet</i>	<i>Feet</i>
0.05.....	800	800	800	800	660	920	300	425
.10.....	800	800	800	800	660	920	300	425
.15.....	800	800	800	800	660	920	300	425
.20.....	1,000	1,000	920	1,000	560	800	260	360
.25.....	1,000	1,000	800	1,000	500	700	225	320
.30.....	950	1,000	720	1,000	450	640	205	290
.40.....	800	900	620	880	380	540	175	250
.50.....	550	550	550	620	340	480	150	220

¹ Assuming maximum nonerosive stream will be used in furrows of adequate cross section; smaller furrows will require smaller streams and shorter runs. Where drainage is a problem, the length of run should not exceed that shown in the local Drainage or Irrigation Guide, whichever is shorter.

Distribution and control of water

Control devices are required to meter the proper amount of water from the field ditch or pipeline into each furrow. The most common devices are siphons for field ditches and gates, valves, or sleeves for pipelines.

Each system needs enough of these devices to take the entire flow of the pipeline or ditch. A few extras make moves easier. The following are common methods of distribution and control of water in furrow irrigation.

Siphon tubes.—Siphon tubes (fig. 48) are widely used because they are easy to set and to move from one location to another. They are made of light

metal, rubber, or plastic. Some metal siphons have gates at the lower ends for controlling the flow. Two or more small tubes can be used in each furrow if the stream is to be cut back after the initial wetting. The stream can be reduced by removing one or more of the tubes, or by using a smaller one. The rate of discharge is affected by the size of the tubes and the variations in the operating heads; i.e., the difference in elevation of the water surface in the supply ditch and at the outlet of the tube (table 8).

Gated pipe.—Gated pipe is made of light-weight metal with small gates spaced to match the furrows. The pipe comes in sections easy for one man to handle and fitted with simple watertight connections. The gates can be adjusted to control the flow of water into the individual furrows (fig. 49). The advantages of gated pipe are: (1) There is no loss

TABLE 8.—Discharge from siphons operating under different heads ¹

Diameter of siphon (inches)	Head in inches—						
	1	2	3	4	5	6	9
	<i>G. p. m.</i>	<i>G. p. m.</i>	<i>G. p. m.</i>	<i>G. p. m.</i>	<i>G. p. m.</i>	<i>G. p. m.</i>	<i>G. p. m.</i>
1/2.....		1.3	1.6	1.8	2	2.1	2.7
3/4.....		3	4	5	5.5	6	7
1.....		4	5	7	8	9	11
1 1/3.....		6	7	8	10	11	13
1 1/4.....		8	10	12	13	15	18
1 3/8.....		10	13	15	17	19	23
1 1/2.....		13	16	18	21	24	28
1 5/8.....		15	18	22	25	28	33
1 3/4.....		17	21	25	28	32	38
1 7/8.....		19	24	29	33	36	44
2.....		21	27	32	36	40	.....

¹ Head is the difference in height of water in supply ditch and at discharge end of tube.



ARK-61933-D

Figure 48.—Siphon tubes distribute water to furrows.



NEB-1748

Figure 49.—Gated pipe delivers water directly into the furrows.

of water between the field ditch and the furrow; (2) it is not necessary to construct head ditches across the crop rows in the field; and (3) the pipe can be uncoupled and laid parallel to the rows or removed from the fields during cultivation, or periods when irrigation is not needed.

Distribution hose.—A vinyl-coated glass, cloth, butyl, plastic, or canvas hose can be used to distribute water to the furrows. Each section is fitted with outlet tubes spaced to match the furrow. The hose usually comes in 100-foot lengths that can be rolled up and carried from field to field. Surface hose has the same advantages as gated surface pipe, except that it is much more susceptible to deterioration by weathering and use.

Buried pipelines and risers.—A distribution system consisting of buried pipelines with risers ending in distribution pots can be used to convey water to the furrows. This system is generally used in orchards and vineyards. It usually requires the highest initial investment, but has the advantage of greatly reducing labor and maintenance costs.

Contour Borders

Contour border irrigation is the application of water to a gently sloping field that has been divided into strips bounded by low earth ridges or levees on the contour. The ridges confine the water to each strip until the required irrigation is completed. For most farm crops, when the desired amount has soaked into the soil the excess is drained off and used to irrigate the next border strip below. In irrigating rice, water is held on the entire field for long periods of time to control weeds.

Where adapted

For successful contour border irrigation, soils should be medium- to fine-textured. They should be able to store at least 1.5 inches of available moisture per foot of depth or at least 3 inches in the root zone of the crop. The intake rate should not exceed 0.5 inch per hour. For rice culture, the soil must have a restricting layer just below the root zone with a permeability rate of not more than 0.01 inch per hour.

Topography should be smooth and reasonably uniform, with a maximum slope of not more than 1 percent. Where slopes in small parts of a field exceed 1 percent, land leveling or grading is required.

A water supply of at least 10 g. p. m. per acre irrigated is needed. The irrigation stream must be large enough to permit rapid flooding of each border strip. A minimum of 225 g. p. m. (0.5 c. f. s.) per acre in the largest strip is recommended. Larger irrigation streams utilize labor more efficiently by permitting one man to irrigate a larger acreage in a day.

Advantages of the contour border method are: (1) Efficient and uniform distribution of irrigation water is easily obtained, (2) maximum utilization can be made of rainfall, (3) adequate drainage facilities are easily provided, (4) operation of the system is simple and easy, (5) initial installation costs are low, and (6) labor and other operational costs are relatively low.

Limitations on the use of contour borders are: (1) They are restricted to the soil and topographic conditions described; (2) land smoothing is required; (3) relatively large irrigation streams are usually required; (4) young crops may be damaged on soils that crust after being wet; and (5) maintenance of border ridges, ditches, and structures is a problem.

In Arkansas and Louisiana where these systems are used extensively, initial installation costs range from \$15 to \$30 per acre, depending upon the land smoothing required. These costs do not include the development of the water supply. After installation, one man can irrigate as much as 300 acres.

It is desirable to smooth the surface of the area to be irrigated by two or more passes with a land-plane, the number of passes depending on the relative smoothness of the existing surface. This smoothing of the surface tends to permit better alignment of the borders, a more uniform application of water, and more effective drainage.

Design of system

A contour border irrigation system in the humid areas should adhere closely to the natural drainage pattern to provide for the removal of excess rainfall (fig. 50). The border ridges follow the contour with one end of each ridge ending at the natural drainage-way, if one exists. W- or V-shaped drainage ditches, which also convey irrigation water, are usually located in the natural depressions (see. B-B, fig. 50).

Border strips.—Where the contour border method is used with row crops, cultivation is usually completed before the border ridges are built. Crop rows, therefore, must be carefully laid out so that when the ridges are built later each row will drain toward the upper side of a ridge and will contain no pockets or high spots.

The desirable vertical interval between border ridges is 0.20 foot. This interval can be increased to 0.40 foot where topography is such that a smaller vertical interval would result in a horizontal interval of less than 40 feet.

To provide uniform penetration of water and rapid

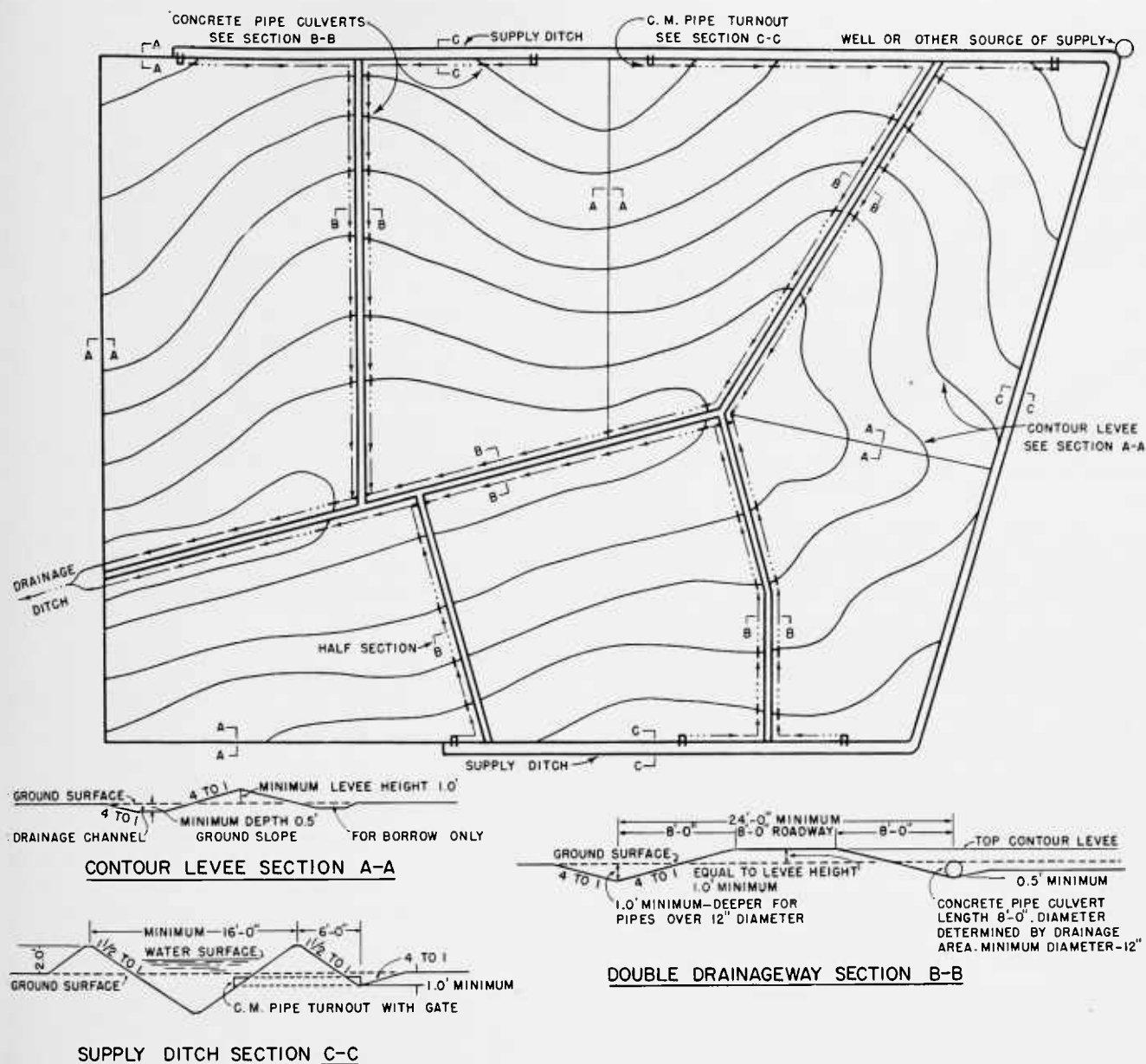


Figure 50.—A typical layout of a contour border system.

removal of the excess, border strips should not exceed 600 feet in length. The area of individual strips should not exceed 2 acres for each cubic foot per second (450 g. p. m.) of water available, and 1 acre per cubic foot per second is better.

Border ridges.—The settled height of the ridges must equal the sum of the vertical interval between them, the depth of water applied, and the freeboard needed. The freeboard should be at least 0.25 foot. An additional 0.30 foot must be provided for settling. Thus, the unsettled ridge height might be computed as follows:

	Feet
Vertical interval between ridges.....	0.20
Depth of water to be applied (3 inches).....	.25
Freeboard.....	.25
Allowance for settling.....	.30
Minimum unsettled height.....	1.00

Where the ridges are temporary, as for rice or row crops, their side slopes should be no steeper than 2 to 1, horizontal to vertical. In permanent pastures the ridges should have side slopes no steeper than 4 to 1 to permit the use of mowing machinery and to resist trampling by livestock.

Distribution and control of water

A drainage ditch, at least 0.50 foot deep and with side slopes no steeper than 2 to 1, is needed along the upper side of each ridge. The ridges are usually constructed with a grader, using the dirt removed from the ditch (sec. A-A, fig. 50).

Where water enters a drainageway from both sides, it consists of two V-shaped ditches with a levee between them. The levee should be wide enough to serve as a roadway, providing easy access to all parts of the field. Where the water enters

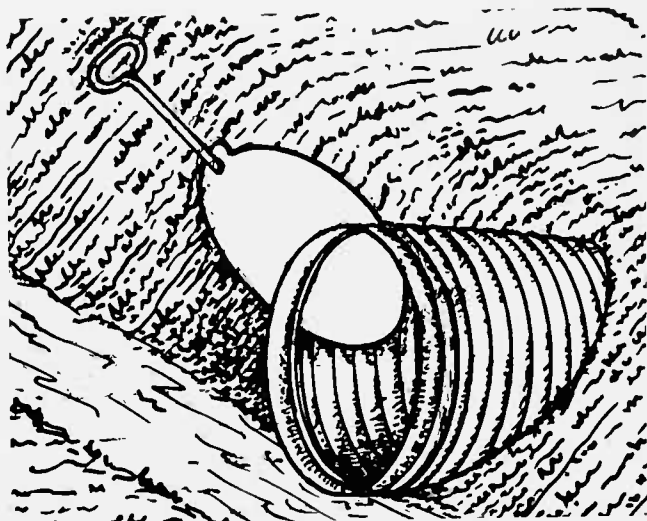


Figure 51.—A corrugated metal pipe turnout for contour border irrigation.

from one side, one ditch and a levee are needed. The drainage ditches must be 0.50 foot deeper than the ditches along the upper sides of the border ridges, or a minimum of 1 foot.

The center levee must be as high as the border ridges. Side slopes of levees should be no steeper than 2 to 1, and in pastures they should be at least 4 to 1.

In order to hold water on the border strips, the ridges must cross the drainageways; drainage is provided by a pipe culvert in the drainage ditch under each border ridge (fig. 51). Usually two 4-foot joints of concrete pipe or an 8-foot section of metal pipe is used. The diameter of the pipe is determined by the drainage area above. The pipe should be at least 12 inches in diameter and large enough to remove 2 inches of water in 24 hours.

Culverts are plugged at their upper end to hold irrigation water on the border strip until the desired amount has soaked into the soil. For irrigating rice, where water is to be held on the field for several days, spillways are installed in the contour ridges to convey the water from one strip to the next and to control its depth.

Supply ditches along the upper side of the area to be irrigated convey the water to the highest border strip in each series. Each ditch consists of two parallel levees built of soil from a borrow area between. Since the system operates by gravity, water is conveyed above ground surface and a head of at least 0.50 foot, and preferably 1 foot, must be provided at the turnouts. Tops of the levees, therefore, must be at least 2 feet above the highest part of the irrigated area. Side slopes usually should be not steeper than $1\frac{1}{2}$ to 1 (sec. C-C, fig. 50).

Water enters the upper border strips through pipe turnouts. An 8-foot section of corrugated metal pipe with an inexpensive light steel gate on the upper end is easy to install and is satisfactory. The diameter of the pipe depends upon the planned rate of flow to the borders and the head available to obtain that flow.

Operation of system

Irrigation with a contour border system begins with the culverts in the drainageway plugged. The turnout gate in the supply ditch is opened, and water enters the upper border strip of a series. When water reaches the desired depth on this strip the first culvert in the drainageway is partially opened, allowing water to flow into the next lower strip; or, in rice irrigation, the water may be controlled automatically by spillways in the contour ridges. When water reaches the desired depth on each strip, it is turned onto the next one in the same way.

After water has been on the upper strip long enough to permit infiltration of the desired amount, the plug in the culvert controlling that strip is removed, and the excess drains off quickly. This process is repeated downslope to complete the irrigation. With careful operation only the excess water on the lowest strip of each series need be drained off as waste.

The time of the first irrigation of row crops is especially important, for flooding may damage young plants. Most row crops should not be irrigated by the contour method until the plants are at least 45 days old.

Graded Borders

A graded or parallel border irrigation system consists of parallel strips of land separated by low earth ridges on a field that has been leveled to a desired grade (fig. 52). The strips are level crosswise between borders and normally run down the main slope. Where the land has been leveled in benches, the strips run across the main slope.

A large stream of water is turned in at the head of a border strip and moves downslope as a sheet confined by the ridges or borders, soaking into the soil as it goes. As soon as the desired amount of water is applied—usually before the sheet has reached the lower end—the water is cut off. When the receding water reaches the lower end the entire strip has been irrigated.

Where adapted

The graded border method is adapted to most soils where depth and topography permit the required land leveling at a reasonable cost and without permanent reduction in soil productivity. Slopes ordinarily should not exceed 2 feet per 100 feet.

This method is adapted to a wide range of soil textures, excepting only those having extremely high or extremely low intake rates. Soils with too high intake rates require very large irrigation streams and very short border strips to avoid excessive water losses by deep percolation at the upper ends of the strips. On the other hand, soils with extremely low intake rates require correspondingly small irrigation streams; with these it is difficult to get adequate coverage and to avoid excessive runoff from the lower ends of the strips.

The graded border method is especially suited to the irrigation of close-growing crops not damaged by

temporary flooding. It is used primarily for irrigating hay crops, pasture grasses, and small grains.

The graded border method has a number of advantages: (1) The initial investment is relatively low, since the border ridges can be constructed cheaply with ordinary farm implements; (2) with a good system one man can irrigate a larger acreage than with some other irrigation methods, and labor costs are correspondingly low; (3) cost of pumping, if any, is low since the system does not operate under pressure; (4) uniform distribution and high water-use efficiencies are possible with proper design, layout, and operation; (5) relatively large irrigation streams can be used efficiently; (6) operation of the system is simple and easy; and (7) properly graded border strips provide for excellent surface drainage if adequate outlet facilities are provided.

On the other hand, this method has the following limitations: (1) It can be used only on certain soils and slopes, as previously discussed; (2) a more precise land-leveling job is required than for other surface methods; (3) relatively large irrigation streams are needed, often in excess of 2 c. f. s. or 900 g. p. m.; (4) light applications, less than 2 inches in depth, are difficult to make efficiently; (5) young crops may be damaged or extra tillage required on soils that bake or crust after being wet; and (6) the border ridges must be maintained and they tend to interfere with mechanized farming.

Design of system

Precise land leveling is essential to successful irrigation by the graded border method. The final slope should not exceed 1 foot per 100 feet in the direction of irrigation for hay crops and small grains. Slopes of up to 2 feet are permissible for irrigation of permanent pastures. The graded slopes should be uniform throughout the length of the border

strips, although some variation can be tolerated to avoid excessive leveling costs. In such cases, the steepest slope in any border strip should be no greater than $1\frac{1}{2}$ times the flattest slope, or the difference between slopes should be no greater than 0.50 foot per 100 feet, whichever is less. The grade should increase or decrease consistently without undulation.

Where the crop to be irrigated is to be rotated with row crops irrigated by the furrow method, the slopes in the direction of irrigation should conform to the requirements of the furrow system.

The border strips should be level crosswise; in no event should the cross slope exceed 0.10 foot in the width of one strip. Greater cross slopes cause the water to concentrate along one side of the strip giving uneven irrigation.

Size of border strips.—The dimensions of border strips depend upon the size of the irrigation stream available, the intake rate of the soil, the slope of the land, and the amount of water to be applied.

This information should be obtained locally by field surveys and from the local Conservation Irrigation Guide. The table of dimensions of border strips and size of irrigation streams (table 9) includes common recommendations from local guides covering a wide range of conditions. These general recommendations should be used only where more specific local information is not available.

The width, or distance between border ridges, is governed largely by the slope of the land and the size of the irrigation stream that is available and can be safely turned into the strip. Where possible, the selected border-strip width should be a multiple of the width of the least flexible farm implement to be used in the field.

The length of a border strip is limited by the size of the irrigation stream that will flow without causing erosion. For example, with a slope of 0.50



MONT-139

Figure 52.—Irrigation with graded borders.

TABLE 9.—*Sizes of border strips and irrigation streams for different slopes and amounts of water applied on different soils*

Slope of border strip (percent)	Width of border strip	Fine-textured soil, intake rate 0.4 in./hr.				Medium-textured soil, intake rate 1.0 in./hr.				Moderately coarse-textured soil, intake rate 2.0 in./hr.			
		2-inch irrigation		4-inch irrigation		2-inch irrigation		4-inch irrigation		2-inch irrigation		4-inch irrigation	
		Irrigation stream	Length ¹ of border strip	Irrigation stream	Length ¹ of border strip	Irrigation stream	Length ¹ of border strip	Irrigation stream	Length ¹ of border strip	Irrigation stream	Length ¹ of border strip	Irrigation stream	Length ¹ of border strip
	<i>Feet</i>	<i>C. f. s.</i>	<i>Feet</i>	<i>C. f. s.</i>	<i>Feet</i>	<i>C. f. s.</i>	<i>Feet</i>	<i>C. f. s.</i>	<i>Feet</i>	<i>C. f. s.</i>	<i>Feet</i>	<i>C. f. s.</i>	<i>Feet</i>
0.25	50	4.2	1,320	2.3	1,320	8.5	1,030	5.7	1,320	8.4	530	8.5	960
.35	50	3.9	1,320	2.2	1,320	6.6	860	5.4	1,320	6.7	450	6.6	800
.50	45	3.2	1,320	1.8	1,320	4.5	720	4.4	1,320	4.5	370	4.5	670
.75	40	2.6	1,320	1.4	1,320	2.9	580	3.0	1,000	3.0	300	3.0	550
1.00	40	2.4	1,300	1.4	1,320	2.4	500	2.4	930	2.4	260	2.4	460
1.25	35	1.8	1,150	1.1	1,320	1.8	450	1.8	840	1.8	230	1.8	410
1.50	30	1.3	1,050	.9	1,320	1.3	400	1.3	760	1.3	210	1.3	370
2.00	30	1.0	890	.9	1,320	1.2	340	1.0	650	1.0	180	1.0	320

¹ Lengths of border strips are for permanent pasture. Where alfalfa, annual hay crops, or small grains are irrigated, border strips should not exceed these lengths or 1,000 feet.

foot per 100 feet, a flow of 0.10 c. f. s. per foot of border-strip width may be used safely. With a slope of 2 feet per 100 feet, the safe size of stream is about 0.035 c. f. s. per foot of width. Thus, the larger streams that can be used safely on the flatter slopes permit longer border strips to be used. On fine-textured soils with slopes of less than 0.2 foot per 100 feet, the length of strips is limited by surface drainage requirements.

The area of the border strip should not be greater than the maximum irrigation stream will cover uniformly without excessive losses in the time allotted for the irrigation set.

Irrigation streams.—The size of the irrigation stream depends on the texture and intake rate of the soil, the size of the border strip, and the depth of application required. Coarse-textured soils with high intake rates require large streams to spread the water over the entire strip rapidly and avoid excessive losses due to deep percolation. Fine-textured soils with low intake rates require smaller ones to avoid excessive losses to runoff from the lower ends of the strips. For the same reason, larger streams are

required for large strips than for small ones, and for shallow applications than for deep ones.

It is important that intake rates of the soil be determined in the field. Soil Conservation Service technicians obtain this information with cylinder infiltrometers (fig. 53). Knowing the intake rate and the slope of a field, an experienced technician can calculate the border-strip dimensions and size of irrigation stream that will give most uniform distribution and greatest efficiency.

Border ridges.—Border ridges need to be high enough to control the flow. They must be higher for the flatter slopes than for the steeper ones. The base of the ridge should be broad so that farming operations can be carried on over it. The sides of the ridge should be no steeper than 2 to 1, horizontal to vertical. Thus, on a steep slope where a ridge of minimum settled height of 4 inches is needed, the base should be at least 24 inches wide. On flatter lands where an 8-inch ridge is needed, the minimum base width should be about 48 inches.

Two implements commonly used to build border ridges are the border disk (fig. 54) and border drag. A variety of other implements can be used. Some, like the border disk, leave shallow ditches along both



LA 61843

Figure 53.—Determining intake rate of a soil with cylinder infiltrometer.



CAL-6974

Figure 54.—Building a border ridge with border disk.

Subirrigation

Subirrigation is a method of applying water beneath the ground surface. It is usually done by creating an artificial water table and maintaining it at some predetermined depth, usually 12 to 30 inches, below the ground surface. Moisture reaches the plant roots through capillary movement upward.

Where Adapted

Several conditions are requisite to successful subirrigation. These are:

(1) An adequate supply of water relatively free of salts must be available throughout the growing season.

(2) The area to be irrigated must be nearly level and comparatively smooth. Land leveling or smoothing is usually required for best results.

(3) There must be a permeable layer, such as organic soil or sand, immediately below the surface to permit rapid movement of water both laterally and vertically.

(4) Beneath the permeable layer must be a barrier against excessive losses through deep percolation. This barrier may be a relatively impervious layer in the substratum or a permanent high natural water table on which an artificial water table can be built.

(5) The distribution system must permit the water table to be raised to a uniform depth below the ground surface of the entire area.

(6) An adequate outlet for drainage of the irrigated area must be available.

This method of irrigation has several major advantages in areas where it is adapted: (1) Subirrigation can be used effectively on some soils that are difficult and expensive to irrigate by other methods, (2) installation costs are low except where water is introduced through tile, (3) labor requirements are low, (4) the method is adaptable to a large variety of crops and does not interfere with tillage practices, (5) high efficiency in water use is possible, and (6) the same system can provide for both irrigation and drainage.

Subirrigation also has rather severe limitations. The principal one is the unusual combination of natural conditions for successful subirrigation, discussed in the following paragraph. Only water of good quality can be used and soils may become saline unless water application is carefully controlled. High fertility may be difficult to maintain.

There are few places in the humid States where all these conditions exist, and they are of limited area. Hence, the opportunity for subirrigation is limited. Among the better-known areas where subirrigation is practiced are the Everglades of south Florida and the Flatwoods of the Florida Coastal Plain. There are smaller scattered areas of organic soils in the Great Lakes States of Michigan, Indiana, Minnesota, Wisconsin, and Ohio. In these States the practice is known as "controlled drainage," since the water table is controlled by a system of



MONT-125

Figure 55.—A permanent turnout in bank of supply ditch.

sides of the border ridges. These ditches need to be filled by blading or smoothing between the ridges; otherwise, the water flows down the sides of the strip in these channels and does not wet the soil evenly.

Distribution and control of water

Water is brought to the heads of the border strips in head ditches, sometimes called "field laterals," or in pipelines. Earth ditches are most economical on gentle slopes; they are satisfactory on medium- to fine-textured soils with moderate to low intake rates. On coarse soils with high intake rates, water losses during conveyance are excessive in unlined ditches. Pipelines are more satisfactory under such conditions.

Where head ditches are used, water flows into the border strips through open turnouts, pipe turnouts, or siphons over the bank of the ditch. Turnouts are usually permanent structures and are used where the border ridges are to be maintained permanently (fig. 55).

In loose sandy soils or where large irrigation streams are desirable, siphons that will discharge up to 2 c. f. s. each are advantageous. One or more siphons can be used to deliver the desired rate of flow to a single border strip. Such large siphons require the use of a priming pump, but they are easy to handle and positive in action. The investment in enough siphons to irrigate a large field is relatively small compared to the cost of adequate permanent turnouts. The use of siphons leaves the head ditch free of obstructions and permits ditch maintenance by machine instead of hand labor.

A system of buried pipelines with an outlet valve in each border strip is most satisfactory from the standpoint of farm operations. Pipelines do not have to be laid out on grade. Water losses in conveyance are negligible. No land is taken from cultivation, and there is no problem of weed control.



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Figure 56.—A subirrigation system using open ditches for water distribution.

structures in drainage canals and additional water normally is not needed for irrigation.

Distribution and Control of Water

Water may be introduced into the soil from open ditches (fig. 56), mole drains, or tile drains. The former method is most widely used since it is relatively inexpensive and is adaptable to all soils that can be subirrigated.

Since the main or supply ditches are used for drainage also, their depths and cross-sectional areas are often determined by the volume of water that must be removed from the area. These ditches usually contain check structures equipped with flashboards to control the water level. The struc-

tures are spaced at vertical intervals not exceeding 6 inches. The flashboards are removed to permit drainage when irrigation is not required.

Feeder ditches, drains, or tile lines are spaced to keep the depth of the water table within limits prescribed for the site.

Mole drains can be used successfully only in organic soils, as in the Florida Everglades.

Tile is sometimes used in the organic soils of Michigan, Indiana, Minnesota, Wisconsin, and Ohio, and in the sands of the Flatwoods area of Florida. The principal deterrent to the use of tile is the high cost of installation which may amount to several hundred dollars per acre. This cost is justifiable only for very high-value crops.

Appendix

Minimum Requirements for the Design, Installation, and Performance of Sprinkler Irrigation Equipment¹

These minimum requirements pertain to the design, installation, and performance of sprinkler irrigation equipment and include dealer-purchaser responsibilities. The design and performance requirements are concerned particularly with those factors that are directly related to land, crops, and farm operations. The dealer-purchaser responsibilities recognize successful operation of a sprinkler system as depending on both buyer and seller.

Part I. Design and Performance

1. *Application Rate.* A portable sprinkler irrigation system, when properly designed and operated, shall meet the following conditions with respect to water application:
 - a. Water shall be applied at a rate that does not cause runoff during the normal operating period nor cause it to stand on the surface of the ground after the sprinkler line is shut off.
 - b. Determination of the proper rate of application shall be the responsibility of the person designing the system. Bare-ground infiltration rates for different types of local soils may be obtained from responsible agricultural technicians. In the absence of such technical advice, the designer may estimate the proper application rate on the basis of past experience with similar soil types.
2. *System Capacity.*
 - a. For regularly irrigated areas, the system shall have the capacity to meet the peak moisture demands of each and all crops irrigated within the area for which it is designed. Sufficient time must be allowed for moving laterals and for permitting cultural practices on the land. The capacity must also allow for reasonable water losses during application periods.
 - b. For supplemental irrigation and/or special uses, the system shall have the capacity to apply a stated amount of water to the design area in a specified net operating period.
3. *Depth of Water Application.* In the design of the system, total depth of application (equivalent rainfall) per irrigation shall be governed by the capacity of the soil to store moisture and the depth of the principal root zone of the crop to be irrigated. Information on both of these

factors may be obtained from agricultural technicians or may be estimated by the designer on the basis of his past experience with similar soil types and crops.

4. *Uniform Water Application.* Since uniformity of application is affected by both pressure in the line and spacing of sprinklers, recommendations for desirable operating pressures and spacings for different types of sprinklers and nozzle sizes shall be obtained from the sprinkler manufacturer.

Differences in pressures at the sprinklers shall be kept to a minimum to assure reasonably uniform distribution of water over the entire design area. A common rule, which should be adhered to as closely as practicable, is to limit pressure differences along a sprinkler lateral to 20 percent of the higher pressure.

Excessive pressure differences in the main or supply line result in widely varying pressures at the head of the laterals. Often these excessive variations cannot be controlled by pipe size alone. Then the only practical alternative is to design for adequate pressure at the lateral takeoff, where pressure in the main will be lowest, and instruct the operator how to regulate pressures into the other laterals by adjusting the takeoff-valve openings.

5. *Crop Damage.* Water shall be applied in a way that will not damage plants or fruit.

Part II. Dealer-Purchaser Responsibilities

A. Dealer Responsibility

1. *Proper Design.* When the system is planned by a dealer or his representative, the dealer shall assume full responsibility for the proper design of the system he proposes to furnish. Design requirements to fit the system to conditions of soil topography, water supply, and crop enterprise shall be ascertained by the dealer either directly or by obtaining such information from recognized reliable sources.

When design requirements are furnished in writing by the purchaser, the dealer's responsibility shall be limited to design of the system to meet the stated conditions.

When plans and specifications are furnished in writing by the purchaser, the dealer's responsibility shall be limited to supplying equipment that will satisfy the requirements of the specifications furnished.

When the purchaser buys the system piecemeal, he absolves all dealers of responsibility for the performance of the system as a unit.

2. *Proper Installation.* The dealer or his representative shall assume full responsibility for the proper installation of the system.

Pumps and power units shall be set on a firm base, and care shall be taken to keep the pump and the motor or engine in proper alignment.

Wiring and starting equipment for electrically operated plants shall comply with approved standards. Electric motors shall be provided with overload and low-voltage protection.

¹This recommendation was sponsored by the Subcommittee on Sprinkler Irrigation, Soil and Water Division, American Society of Agricultural Engineers, and received the official endorsement of the Sprinkler Irrigation Association at its annual convention at Biloxi, Miss., Nov. 1952. It was approved Feb. 1953 as an official ASAE recommendation.

Internal-combustion engines shall be provided with protective devices. Thermostats shall be supplied that stop the engine when water or oil temperatures exceed the safety point. Where conditions are such that a failure of the water supply might cause the pump to lose its prime, the pumping plant shall be protected by a device that stops the engine. These devices may be dispensed with where conditions are such that there is little probability of water-supply failure or when the pumping plant is constantly attended.

3. *Operating Instructions.* The dealer or dealers furnishing equipment required for a complete sprinkler system shall furnish the purchaser, in writing, such instructions, performance charts, and layout drawings as are required to insure proper operation, in accord with design conditions and normal expected life for the type of equipment furnished.

4. *Performance Warranty.* When a dealer or associated group of dealers assumes responsibility for designing and installing a sprinkler irrigation system, a warranty shall be furnished stating specially the performance expected for water-application rate, capacity, rate of coverage for a specific design area serving specific crops, and crop acreages as stated by the purchaser and mutually understood to be the basis for the design.

Warranty shall be based on trial of the system during operation under the range of operating conditions imposed on the system. The warranty shall not be expected to cover any conditions that are beyond reasonable control of the dealer either in design or in installation. Values used for infiltration rate, peak-use rate of moisture by crops, or capacity of soils to retain water for plants cannot be expected to be accurate for every condition of soil. Evidence that the dealer has made reasonable efforts to obtain values from reliable sources shall be sufficient reason to absolve him from responsibility if such values do not represent local conditions.

When a dealer or dealers assume responsibility for the installation of a system in accord with specifications supplied by the purchaser, a warranty shall be furnished stating the performance expected as to friction loss in the system, pump and engine motor characteristics, and other pertinent data pertaining to the specifications.

5. *Equipment Warranty.* The dealer or dealers assuming responsibility for the installation of the system shall furnish warranties covering the quality of material and workmanship of each piece of equipment furnished in accord with the original manufacturer's guarantee, and shall provide for replacement of defective parts shown to have failed because of poor-quality materials or poor workmanship.

6. *Maintenance and Repair Service.* Dealers selling

sprinkler irrigation systems in a territory shall maintain an inventory of replaceable parts and required equipment repair service. The extent of this available service shall be such that users in the territory will be assured of reasonable service that will avoid crop loss due to shut-down of a system for replacements or repairs.

B. *Purchaser Responsibility*

1. *Operation in Accord with Instructions.* The purchaser and user of a sprinkler irrigation system shall assume responsibility for failure of the system to perform properly if, after receiving all data furnished by the dealer, he fails to operate the system in accord with all conditions assumed in the design of the system. To obtain full life of all equipment, the user shall observe the stated limits of operating conditions set forth by the manufacturer.

2. *Care and Maintenance Recommendations.* The purchaser shall follow the dealer's recommendations for care and maintenance of the equipment. This applies to periods of use as well as nonuse of the equipment.

Part III. *Definitions*

Design Area. The specific land area which the supplier or designer and the purchaser mutually understand is to be irrigated by the sprinkler system.

Sprinkler Irrigation System. All equipment required to apply water to the design area, from the source of water supplying the system to the revolving sprinkler, nozzles, or perforated pipe.

If water is already available to the design area, the system includes only the equipment required to develop the necessary pressure and apply the water to the area.

If both water and pressure are available, as in the case of an existing pressure line, the system includes only the equipment required to take the water under pressure from the supply line and apply it to the design area.

Sprinkler Lateral. A line of portable pipe or tubing with sprinklers, nozzles, or perforations along the line. A lateral may be one of several operated from a common main supply line, or it may be a single unit supplied directly from the water source.

Application Rate. The equivalent rainfall rate expressed in inches of water depth per hour (acres-inches per acre per hour). For system with rotating sprinklers, the rate is computed on the basis of the spacing of lateral settings, the spacing of the sprinklers along the lateral, and the average discharge of the sprinklers. For perforated pipe systems, the application rate is computed from lateral spacings, length of lateral, and average flow into the lateral.

Infiltration Rate. The rate at which soil will take in water during the irrigation period, expressed in inches of water depth per hour.

Peak-Moisture Demand. The maximum demand that occurs during periods of maximum temperature and crop growth. This peak demand for moisture on the part of a crop results from transpiration by plants and direct evaporation from the soil.

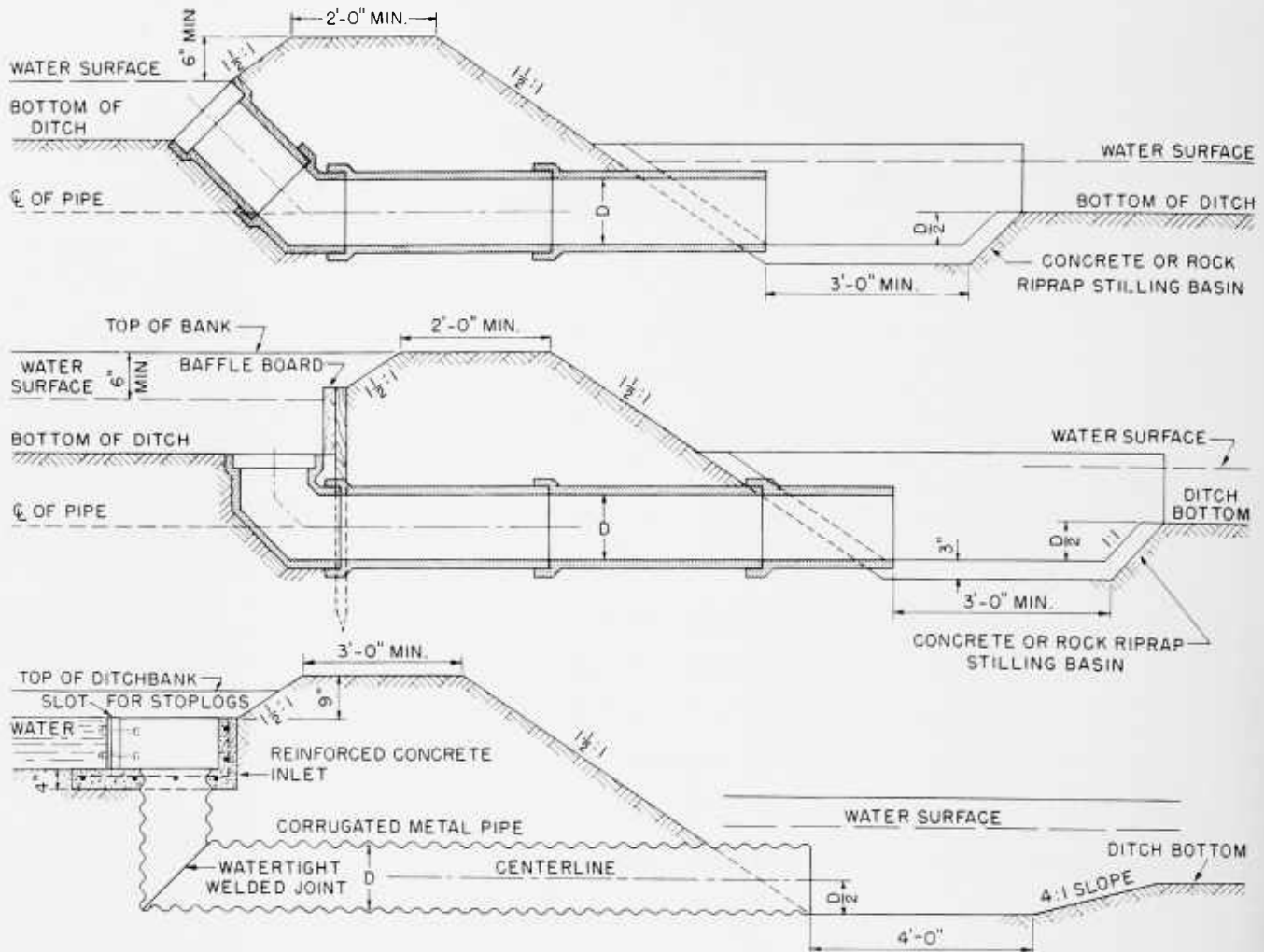
Average Water-Application Rates (Inches Per Hour) from Sprinklers ¹

Spacing (feet)	Gallons per minute from each sprinkler—																																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	25	30	35	40	50	60	70	80	90	100	110	120	200	300	
20×20	0.24	0.48	0.72	0.97	1.21	1.45	1.70	1.94																											
20×30	.16	.32	.48	.64	.80	.96	1.13	1.29	1.45	1.61	1.77	1.93	2.10																						
20×40	.12	.24	.36	.48	.60	.72	.85	.97	1.09	1.21	1.33	1.45	1.57	1.70	1.81	1.93	2.06	2.18																	
20×50	.10	.19	.29	.39	.48	.58	.68	.77	.87	.97	1.06	1.16	1.26	1.36	1.45	1.55	1.64	1.74	1.84	1.94															
20×60	.08	.16	.24	.32	.40	.48	.56	.64	.72	.81	.88	.97	1.05	1.13	1.21	1.29	1.37	1.45	1.53	1.61	2.02														
25×25	.15	.31	.46	.62	.77	.93	1.09	1.24	1.40	1.55	1.70	1.86	2.02																						
30×30	.11	.21	.32	.43	.54	.64	.75	.86	.97	1.07	1.18	1.29	1.39	1.50	1.61	1.72	1.83	1.93	2.04	2.15															
30×40		.16	.24	.32	.40	.48	.56	.64	.72	.81	.89	.97	1.05	1.13	1.21	1.29	1.37	1.45	1.53	1.61	2.02														
30×50		.13	.19	.26	.32	.38	.45	.52	.58	.64	.71	.77	.84	.90	.97	1.03	1.09	1.16	1.22	1.29	1.61	1.93	2.25												
30×60			.11	.16	.21	.27	.32	.37	.43	.48	.54	.59	.64	.70	.75	.81	.86	.91	.97	1.02	1.07	1.34	1.61	1.87	2.14										
40×40		.12	.18	.24	.30	.36	.42	.48	.54	.60	.66	.72	.78	.84	.90	.96	1.02	1.09	1.14	1.20	1.51	1.81	2.11												
40×50		.10	.14	.19	.24	.29	.34	.39	.43	.48	.53	.58	.63	.68	.73	.78	.82	.87	.92	.97	1.21	1.46	1.70	1.94											
40×60			.12	.16	.20	.24	.28	.32	.36	.40	.44	.48	.52	.56	.60	.64	.68	.72	.77	.81	1.01	1.21	1.41	1.61	2.01										
40×80			.09	.12	.15	.18	.21	.24	.27	.30	.33	.36	.39	.42	.45	.48	.51	.54	.57	.61	.76	.91	1.06	1.21	1.52	1.82	2.12								
50×50			.12	.15	.19	.23	.27	.31	.35	.39	.43	.46	.50	.54	.58	.62	.66	.70	.73	.77	.97	1.16	1.36	1.55	1.93	2.32									
50×60			.10	.13	.16	.19	.22	.26	.29	.32	.35	.39	.42	.45	.48	.52	.55	.58	.61	.64	.81	.97	1.13	1.29	1.61	1.93									
50×70				.11	.14	.17	.19	.22	.25	.28	.30	.33	.36	.39	.41	.44	.47	.50	.52	.55	.69	.83	.96	1.10	1.38	1.64	1.93	2.21							
50×80				.10	.12	.14	.17	.19	.22	.24	.27	.29	.31	.34	.36	.39	.41	.44	.46	.48	.61	.73	.85	.97	1.21	1.46	1.70	1.94	2.18						
60×60				.11	.13	.16	.19	.21	.24	.27	.30	.32	.35	.38	.40	.43	.46	.48	.51	.54	.67	.81	.94	1.08	1.35	1.62	1.88	2.16							
60×70					.11	.14	.16	.18	.21	.23	.25	.28	.30	.32	.34	.37	.39	.41	.43	.46	.57	.69	.81	.92	1.15	1.38	1.61	1.84	2.08						
60×80					.10	.12	.14	.16	.18	.20	.22	.24	.26	.28	.30	.32	.34	.36	.38	.40	.50	.61	.71	.81	1.00	1.21	1.42	1.62	1.82	2.02	2.22				
70×70							.14	.16	.18	.20	.22	.24	.25	.28	.30	.31	.33	.36	.37	.39	.49	.59	.69	.79	.98	1.18	1.38	1.58	1.78	1.97	2.16				
70×80							.12	.14	.16	.17	.19	.21	.23	.24	.26	.28	.29	.31	.33	.34	.43	.52	.60	.69	.86	1.04	1.21	1.39	1.56	1.73	1.91	2.08			
70×90								.12	.14	.15	.17	.18	.20	.22	.23	.25	.26	.28	.29	.31	.38	.46	.54	.62	.77	.92	1.08	1.23	1.39	1.54	1.70	1.85			
80×80								.12	.14	.15	.17	.18	.20	.21	.23	.24	.26	.27	.29	.30	.38	.45	.53	.61	.75	.90	1.06	1.21	1.36	1.51	1.66	1.81			
80×90								.11	.12	.13	.15	.16	.17	.19	.20	.21	.23	.24	.26	.27	.33	.40	.47	.54	.67	.80	.94	1.07	1.21	1.34	1.48	1.61			
80×100								.10	.11	.12	.13	.15	.16	.17	.18	.19	.21	.22	.23	.24	.30	.36	.42	.48	.60	.72	.85	.97	1.09	1.21	1.33	1.45	2.42		
100×100										.10	.11	.12	.13	.14	.14	.15	.16	.17	.18	.19	.24	.29	.34	.39	.48	.58	.65	.77	.87	.97	1.07	1.16	1.94		
120×132												.10	.11	.12	.13	.14	.14	.15	.16	.17	.18	.19	.24	.29	.34	.39	.48	.58	.65	.77	.87	.97	1.07	1.16	1.94
																		.10	.11	.12	.12	.15	.18	.21	.24	.30	.37	.43	.49	.55	.61	.67	.73	1.22	1.84

For other discharges and/or spacings, use the following formula:
 $R = (96.3)(g. p. m.)$
 $S_l \times S_m$
 where R=application rate, inches per hour
 g. p. m.=discharge from sprinkler, gallons per minute
 S_l =spacing of sprinklers on lateral
 S_m =spacing of lateral on main

¹ From "Sprinkler Irrigation," Sprinkler Irrigation Association, 1955.

Drops and Checks for Use in Irrigation Ditches



2:1 SLOPE TO PERMIT
NAPPE VENTILATION
AT SIDES

